AD NUMBER

AD-844 934

CLASSIFICATION CHANGES

TO **UNCLASSIFIED**

FROM **NEVER CLASSIFIED**

AUTHORITY

U.S. Army Materiel Command, Washington, DC; October 1968.

19990301073

UNCLASSIFIED

AD NUMBER

AD-844 934

NEW LIMITATION CHANGE

TO

DISTRIBUTION STATEMENT - A

Approved for Public Release; Distribution Unlimited.

LIMITATION CODE - 1

FROM

DISTRIBUTION STATEMENT - NONE

No Prior DoD Distribution Security Control Statement.

AUTHORITY

USAARDCOM ltr., dtd March 16, 1981.

THIS PAGE IS UNCLASSIFIED

REPRODUCTION QUALITY NOTICE

This document is the best quality available. The copy furnished to DTIC contained pages that may have the following quality problems:

- Pages smaller or larger than normal.
- Pages with background color or light colored printing.
- Pages with small type or poor printing; and or
- Pages with continuous tone material or color photographs.

Due to various output media available these conditions may or may not cause poor legibility in the microfiche or hardcopy output you receive.

☐ If this block is checked, the copy furnished to DTIC contained pages with color printing, that when reproduced in Black and White, may change detail of the original copy.

BRL MR 1943

AD844934

BRL

AD

MEMORANDUM REPORT NO. 1943

COMPARISON OF THE EXTERIOR BALLISTICS OF THE M-193 PROJECTILE WHEN LAUNCHED FROM 1:12 IN. AND 1:14 IN. TWIST M16A1 RIFLES

Maynard J. Piddington

October 1968

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Commanding Officer, U.S. Army Aberdeen Research and Development Center, Aberdeen Proving Ground, Maryland.

U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 1943

OCTOBER 1968

COMPARISON OF THE EXTERIOR BALLISTICS OF THE M-193 PROJECTILE WHEN LAUNCHED FROM 1:12 in. AND 1:14 in. TWIST M16A1 RIFLES

Maynard J. Piddington

Exterior Ballistics Laboratory

RDT&E Project No. 1T650212D620

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

MEMORANDUM REPORT NO. 1943

MJPiddington/pp
Aberdeen Proving Ground, Md.
October 1968

COMPARISON OF THE EXTERIOR BALLISTICS OF THE M-193 PROJECTILE WHEN LAUNCHED FROM 1:12 in. AND 1:14 in. TWIST M16A1 RIFLES

ABSTRACT

The results of an exterior ballistics test of the M-193 ball projectile when launched from the M16A1 rifle are presented and discussed. Rifles with twists of 1 turn in 12 inches and 1 turn in 14 inches were used in the tests. Data were gathered from test firings at the small Aerodynamics Range and the Transonic Range of the Ballistic Research Laboratories and from a temporary range set up in the Climatic Hangar at the Eglin Air Force Base, Florida. Tests at Eglin were conducted at air temperatures ranging from +125 deg. F to -65 deg. F.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF SYMBOLS

C_D = $\frac{\text{Drag Force}}{(1/2)\rho V^2 S}$

*C_{M_α} = $\frac{\text{Static Moment}}{(1/2)\rho V^2 S \ell \alpha}$

*$C_{M_q} + C_{M_{\dot\alpha}}$ = $\frac{\text{Damping Moment}}{(1/2)\rho V^2 S \ell \frac{q\ell}{V}}$

C_{N_α} = $\frac{\text{Normal Force}}{(1/2)\rho V^2 S \alpha}$

$C_{M_{p\alpha}}$ = $\frac{\text{Magnus Moment}}{(1/2)\rho V^2 S \ell \frac{p\ell}{V} \alpha}$

σ = standard deviation = $\sqrt{\frac{\Sigma(\text{Resid.})^2}{\text{No. of Observations} - 1}}$

δ = Magnitude of yaw

$\overline{\delta^2}$ = Mean squared yaw over the range of observations

S = $\pi d^2/4$

ρ = air density

α = angle of attack

$\phi'_{1,2}$ = turning rates

$\lambda_{1,2}$ = damping rates

---

*Negative values of C_{M_α} and $C_{M_q} + C_{M_{\dot\alpha}}$ indicate moments which oppose α and $\dot\alpha$ respectively and are therefore stabilizing. A positive value of $C_{M_{p\alpha}}$ indicates a side moment which tries to rotate the missile's nose about its trajectory in the direction of spin.

TABLE OF SYMBOLS (Continued)

cg	= center of gravity
C.I.	= Center of Impact
d	= body diameter of projectile
I_x	= axial moment of inertia
I_y	= transverse moment of inertia
$K_{1,2}$	= yawing vectors
ℓ	= reference length (for this report ℓ = d = .223 inch)
L	= length of projectile
M	= Mach number
N	= Twist rate
o	= subscript denoting initial conditions
p	= rolling velocity
q	= angular velocity
Rd	= round number
s	$= \dfrac{2I_x^2p_o^2}{\pi I_y V_o^2 d^3 \rho C_{M_\alpha}}$ = gyroscopic stability factor
SN	= Serial Number
S_L	= radius of swerve
V	= velocity of missile
WT	= Weight

INTRODUCTION

The program reported is the Exterior Ballistics portion of a larger effort involving several divisions of the Ballistic Research Laboratories (BRL). The program was carried out in response to a request from the Project Manager-Rifles to evaluate the relative effectiveness of the M-16 rifles with barrels of two different twist rates; one turn in 14 inches of travel and one turn in 12 inches of travel.

The amount of spin required to stabilize a bullet depends on various parameters, such as: bullet shape, muzzle velocity, air density and physical properties (including center of mass location, moments of inertia, etc.) A relationship of these various parameters, including spin, yields the gyroscopic stability factor, s, and for a projectile to be gyroscopically stable this relationship must be equal to or greater than one.

Most earlier small arms projectile designs have had values of s considerably greater than one, usually greater than two, and hence they were not appreciably affected by small variations in the properties which influence the value of s. One might expect that variations in the physical parameters, whether incurred during manufacture or launch, could cause a ± 10 percent variation in s. In addition, flight environment, particularly air density, can cause a 25 percent decrease in s when going from 70°F to -65°F. A projectile having a stability factor of 2 at 70°F will not be seriously effected in its flight behavior when s drops to 1.35 for -65°F.

The M-16 rifle system, however, launches a projectile which has s values considerably below 2 and hence is much

more susceptible to changes in air density and to other variations in the parameters which determine s. For example, the gyroscopic stability factor of the M-193 when launched from the M-16A1 rifle with a twist of one turn in 12 inches (1:12 in.) is about 1.45 at 70°F and decreases to a value of about 1.09 at -65°F. For the same bullet launched from a 1:14 in. twist barrel, s has a value of about 1.14 at 70°F and about .85 (theoretical) at -65°F.* As the gyroscopic stability factor approaches unstable values, the flight characteristics of the bullet will deteriorate and could drastically change. The main objective of the Exterior Ballistics Laboratory (EBL) study was to determine precisely how serious an effect reduced values of gyroscopic stability would have on the flight characteristics of the projectile.

In order to perform this task, it was necessary for members of the EBL to travel to the Air Proving Ground Center at Eglin, Fla. to conduct a test of the M-16A1 in the Climatic Hangar[(1)**] where test temperatures ranging from 125°F to -65°F over a range of 70 meters were available. Two rifles with 1:12 in. twist barrels and two with 1:14 in. twists were tested at five temperatures: 125, 70, 0, -30, and -65°F.

It was desirable to use rifles which were currently being produced by Colt Manufacturing Company, but this was possible only for the 1:14 in. twist guns which were part of the "1000 barrel" tests.*** The 1:14 in. twist barrels had been prerated, on the basis of Colt tests, one as having "average" dispersion (7.5 in. maximum spread at 100 yds) and one as having good dispersion (4.0 in. maximum spread at 100 yds). The 1:12 in. twist rifles were selected from the

*Temperature effect on stability factor assumes standard sea level pressure.

**References are found on page 50.

***A special test to compare dispersion of the two twist rifles.

stock pile at APG and were assumed to be typical of current production rifles.

Since it was not practical in the time allotted for this investigation to conduct separate studies on the causes of the variations in the parameters in s, it was necessary to fire a sufficient number of rounds from each barrel at each temperature so that the results would depict these variations. Fifteen rounds per condition were selected as a compromise between statistical desirabilities and available time. Fewer than fifteen rounds were tested at 125°F because of other test commitments of the Eglin installation. The selection of the 125°F test cases for any necessary curtailment was because of the probable lower relevance of the higher stability data.

The individual photographic equipment used in the tests were the same as utilized in the Aerodynamics Range[2] at the BRL. Ten shadowgraph stations using two orthogonal 28 x 36 cm plates were positioned over the 70 meters and yaw cards were placed at the maximum range (70 meters) to record the dispersion.

Measurements obtained from the shadowgraph and yaw cards were used to determine the following as functions of temperature and twist:

1. Dispersion (at approximately 70 meters).
2. Muzzle velocity.
3. First maximum yaw.
4. Gyroscopic stability factor near the muzzle.
5. Maximum yaw at about 70 meters.
6. Velocity at about 70 meters.
7. Variations in 2, 3, 4, 5, and 6.

One month's test time (August '67) was required to complete the firings with considerable assistance furnished

by the personnel of the Climatic Hangar. After some measurements had been made and preliminary evaluations conducted, it became apparent that additional data were urgently required to permit the WSL to conduct properly their phase of the evaluation. The magnitude of yaw at impact often plays an important role in the analysis of a small arms weapon system. WSL requested that flight yaw at ranges greater than 70 meters be obtained.

To obtain such data, five Aerodynamics Range shadowgraph stations were hastily assembled in the Transonic Range[3] of BRL. 30 rounds were then fired from each of two weapons (one 1:12 in. and one 1:14 in. twist) at ranges of about 175, 250, 340, and 450 meters. At these ranges, it was assumed that the initial yaw transients had damped out and that the yaw remaining was due to some phenomena characteristic of the bullet. The data obtained from these firings, as a function of range and twist (at approximately 70°F), were terminal yaw (commonly referred to as limit cycle yaw[4]) and velocity.

For purposes of the exterior ballistics portion of this report, these two tasks mentioned previously will be referred to as:

1. Eglin Test.
2. Limit Cycle Test.

EXPERIMENTAL PROCEDURE

1. Eglin Test

Six stations observing about 5.79 meters of trajectory were positioned near the muzzle of the gun (Figure 1). Four stations covering about 3.35 meters of trajectory were located near the target (70 meters). All stations were carefully surveyed into position and then resurveyed at

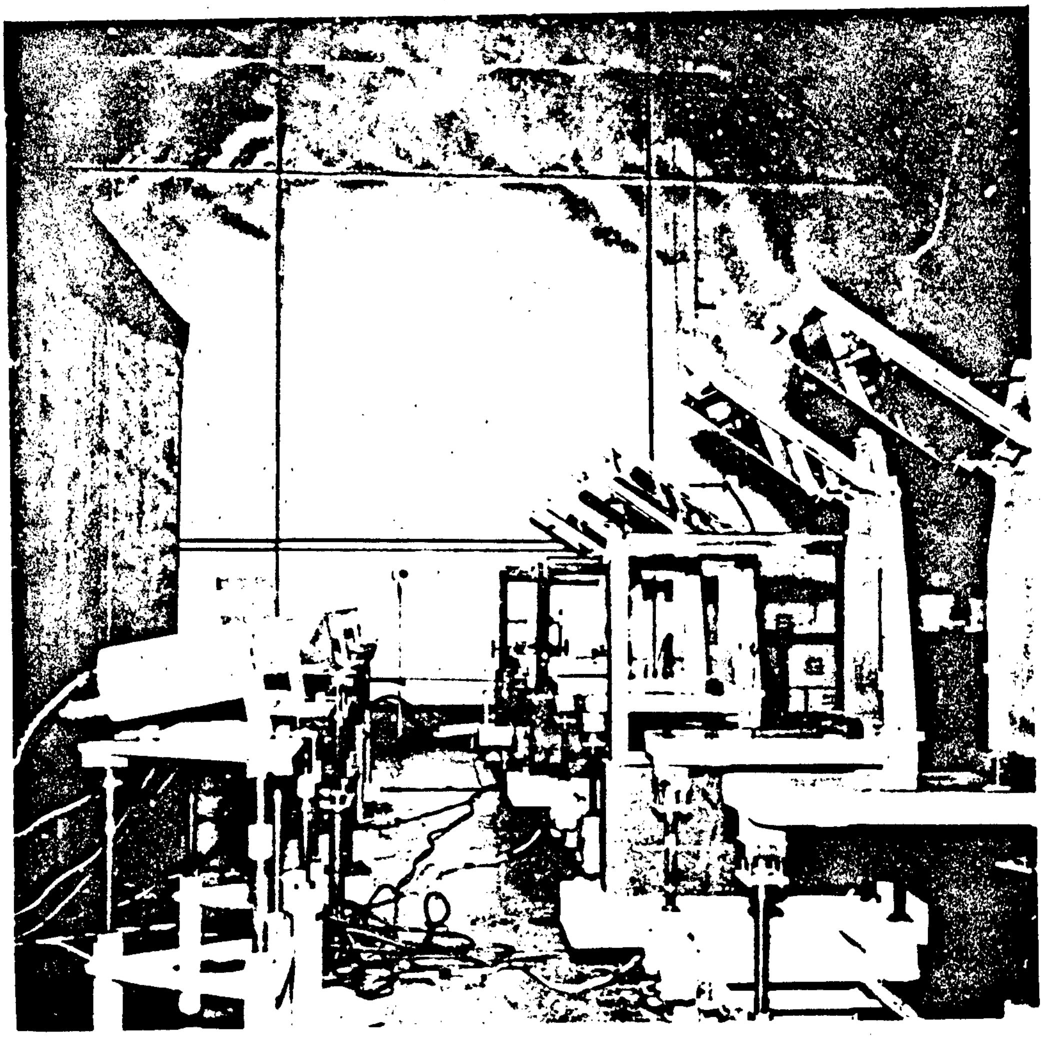

Figure 1. Station Setup at Eglin

various temperatures to insure that the range had not moved significantly because of a change in temperature. If changes did occur, then necessary corrections to the data were made.

The time of flight was recorded at eight of the stations (six in the first group and two in the last). In addition to yielding velocity near the muzzle and near the target, these were used to obtain a fair evaluation of the drag force coefficient.

The guns were separately mounted in a Frankford rest (Figure 2). The rounds were fired into a bullet catcher located behind the target. To protect the equipment at the target from being hit by stray rounds, a protective barricade with about a 38 cm hole was placed directly in front of this group. All guns and ammunition were allowed to temperature soak sufficiently before firing commenced.

2. Limit Cycle Test

Five stations were used in this test located to observe the yawing motion over a period of either 2.74 meters (early phases), or 3.05 meters (later phases). Times of flight were recorded on three of the stations to yield velocity data.

The guns were mounted in a Frankford rest. To obtain data at the various ranges, the gun position was moved relative to the stations and a barricade was used to protect the stations from damage.

LIMITATIONS OF THE DATA

1. Ammunition

Only one lot of ammunition was used in all of the EBL tests. As a result, lot-to-lot variations are not

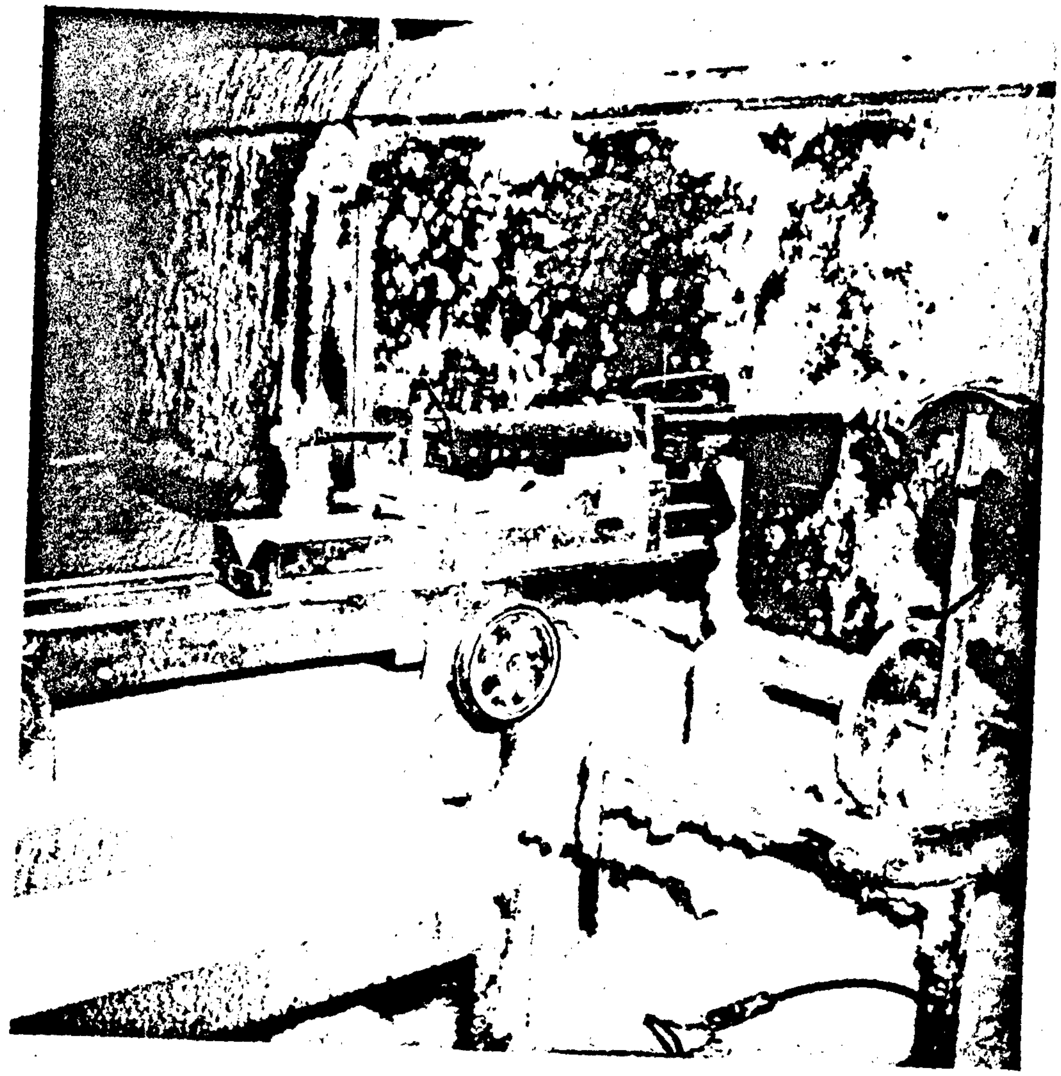

Figure 2. Frankford Rest with Rifle

indicated in the results. The ammunition used does not have a specific production lot number but is designated as LC-SP-412. The rounds were obtained from the production line at Lake City Arsenal in June 1967. EBL was assured by the office of the project manager that the ammunition would meet the necessary acceptance requirements.

LC-SP-412 is ball ammunition using ball propellant. It has not been determined how this lot of ammunition compares to the other lots currently being used in the M-16A1 rifle system.

2. Rifles

The 1:14 in. twist rifles were new and had very few rounds fired from them (estimated as less than 100). The 1:12 in. twist rifles used in the tests were in good condition but much older, and no record was available on how many rounds had previously been fired from them.

The number of rifles tested, of course, was extremely small and can not be confidently compared to an "average" 1:12 in. or 1:14 in. production rifle.

3. Aerodynamic Characteristics

In order for the Computing Laboratory of BRL to obtain the necessary velocity and yawing histories of the projectile, a knowledge of the aerodynamic characteristics of the bullet is required. Because of the time frame of the program, however, only a limited new determination was made with a basic reliance on earlier tests.[5] The new data obtained resulted from rounds launched in the range at BRL from four rifles. Two of these rifles had a 1:12 in. twist and two had a 1:14 in. twist. Two rounds were test fired from each weapon at standard muzzle velocity; the data were reduced in the normal manner. The results are

listed in Table 1 and can be compared to the results of a previously tested round which can be found in Reference 5. At standard muzzle velocity, the data agree quite well with the data in BRL MR 1758 with only one apparent exception. The overturning moment coefficient, C_{M_α}, for the LC-SP-412 round is about 8 percent larger than previously determined. This causes a decrease in the stability factor and is an indication of the variability from lot-to-lot in the ammunition.

DETERMINATION OF RESULTS

1. Velocity and Drag Force Coefficient (Eglin Test)

The velocity, V, and drag force coefficient, C_D, were obtained for each round from a least squares fit of time as a cubic in distance. These values were computed at a point approximately 4.6 meters in front of the rifle. The velocities were then extrapolated to yield muzzle velocities.

For various reasons, time measurements were not always recorded in the second group of stations. Without this longer-base-line data, drag computations were not very accurate. Such rounds, as a rule, produced no drag or downrange velocity data.

2. Maximum yaws (Eglin Test)

The first maximum yaw, $\delta_{o\ max}$, and the maximum yaw, δ_{max}, at about 70 meters were obtained from faired curves of the total yaw as a function of range. A typical example of such curves is shown in Figure 3. The measured values are represented by the circles which could include a point at the rifle muzzle. Although no shadowgraphs were taken at this position, it is reasonably safe to assume that the yaw at this point was very nearly zero.

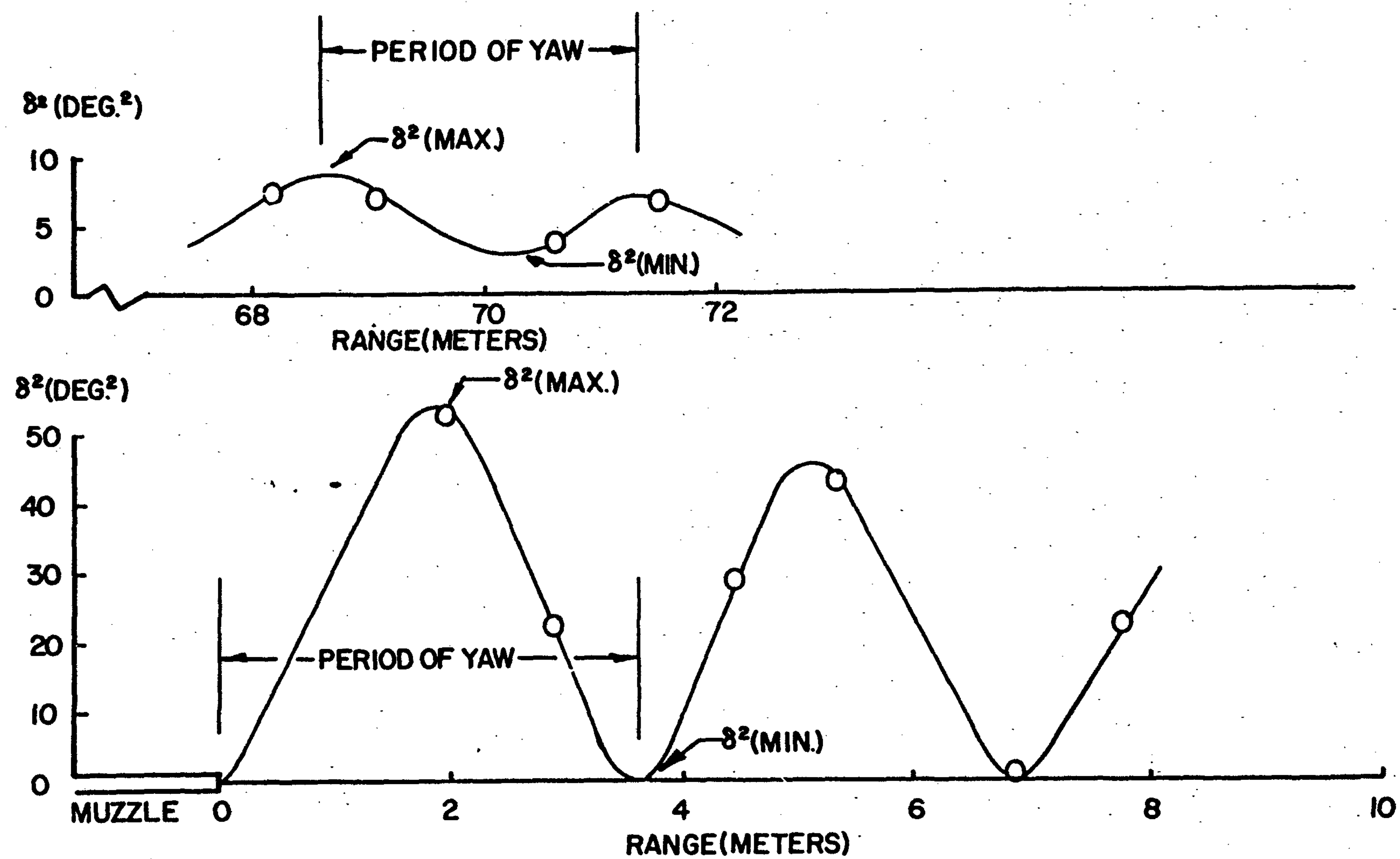

Figure 3. Yaw Squared vs Distance
Rd. 29 (1:12 in. Twist) 70^{0}F

Figure 3 indicates the magnitude and location of the first maximum yaw and the period of yaw near the muzzle. Also indicated is the magnitude of the minimum yaw near the muzzle which is very nearly zero for this round and for nearly all other rounds tested, regardless of the magnitude of the first maximum yaw.

At 70 meters, the maximum, minimum, and sometimes the period of yaw are indicated. At this range, the minimum yaw is most likely not zero. Because of the aerodynamic and dynamic characteristics,[5] the nutational mode of yaw is damping much more rapidly than the precessional mode. It is probable that only the precessional yaw remains and this mode may be slowly damping, remaining constant, or even slowly growing. An insufficient number of observations were made at this location for a complete determination of the yaw characteristics. Only an average approximate position of the maximum yaws can be given both at the gun and at 70 meters since these positions vary by as much as several feet from round to round.

3. Stability Factor (Eglin Test)

The stability factor, s, was determined from the yawing motion of each projectile using only the yaw observed in the first group of stations together with an assumed value of zero yaw at the muzzle. Since only the epicyclic turning rates are required to determine s, the yaw equation was slightly modified so that these values could be easily obtained.

In addition to s, values of the overturning moment coefficient, C_{M_α}, and the twist rate, N, imparted to the bullet were determined for each round. In determining C_{M_α} and the twist rate, average values of the moments of inertia

were used since it would have been impossible to obtain these values for each round tested. Consequently, C_{M_α} and N reflect the variation in moments of inertia. s on the other hand, is a true indication of the stability factor as determined from the yawing motion of each round. All three values were determined at a point located about 4.6 meters in front of the gun.

This method of analysis can be used with confidence only when the stability factor is greater than 1. When s_o is less than 1, the projectile is initially unstable. The yaw history becomes abnormally high but otherwise often appears similar to that of a stable bullet because high yaw phenomena control the instability. The linearized yaw equation used does not recognize these effects and, in fitting, ascribes to the motion a pseudo value of s slightly larger than 1. Since the linearized assumptions used in the fit are obviously violated, no reductions were performed on those rounds which had theoretical s values less than unity. Careful consideration must be given to those determinations yielding s values which lie between 1 and about 1.1 to make sure that these rounds were not, in fact, initially unstable.

An example of such a round is shown in Figure 4. Even though the period of yaw is apparently quite large, the general yawing motion is such as to indicate that the bullet is gyroscopically stable, which for all practical purposes, it is, but not initially. The bullet emerged from the barrel with insufficient spin to stabilize it and soon thereafter started to "tumble". It never completed this motion for as the yaw began to grow it became less unstable until finally s was larger than 1. With $s > 1$, the yawing motion went into an apparently normal epicyclic motion. The result of this initial instability was an increased yaw and a probable increase in dispersion.

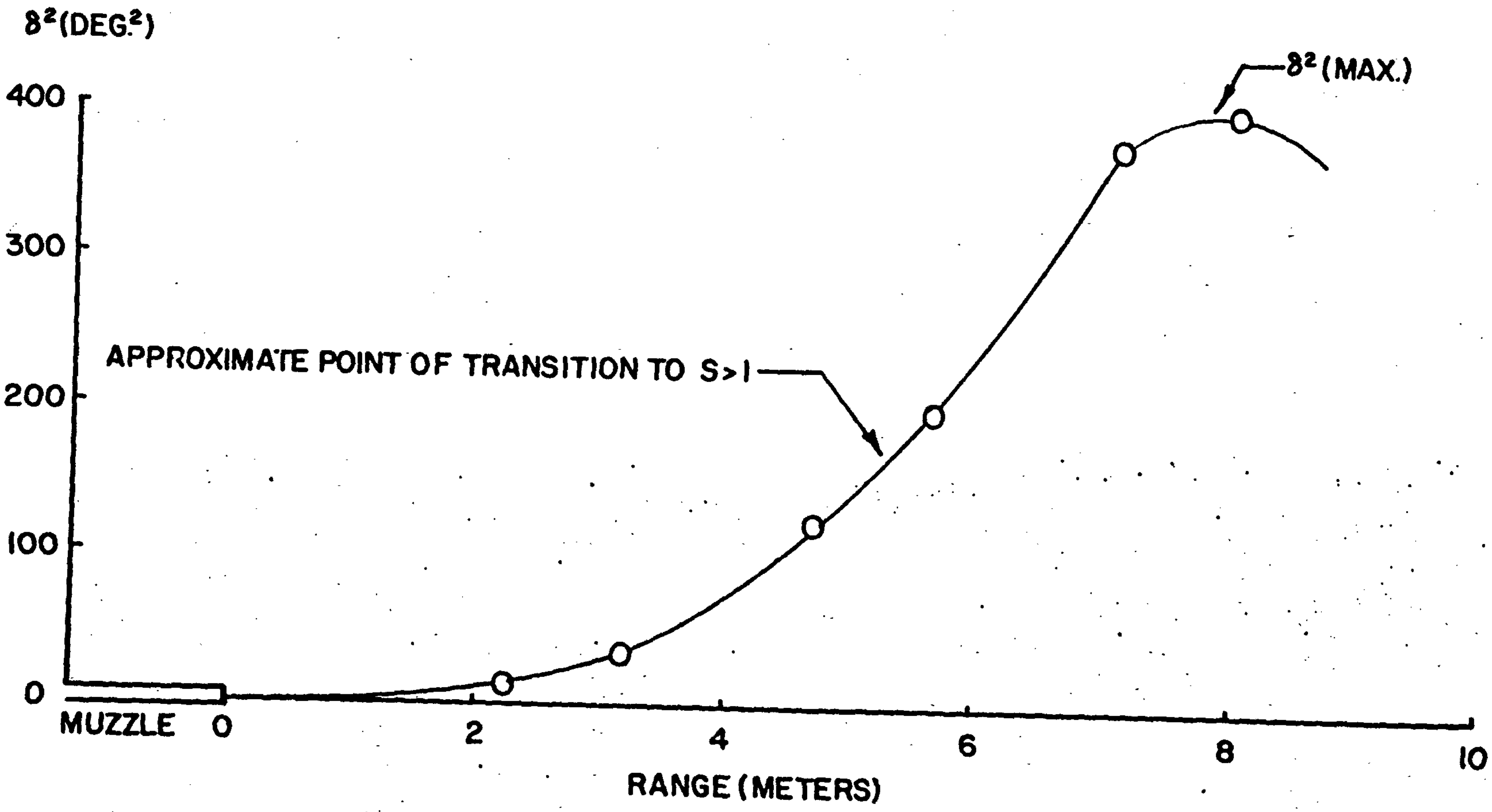

Figure 4. Yaw Squared vs Distance
Rd. 114 (1:14 in. Twist) 0^{0}F

4. Dispersion (Eglin Test)

Dispersion calculations were performed on data in two ways. The first was to use only those data observed from the photographic station located at about 69 meters. This determination was made on 15 rounds for each condition. The second was to perform the calculation on measurements obtained from yaw cards at about 70 meters which, in general, was for about 10 additional rounds fired with no photographic coverage for each condition. Then both sets of data were combined to yield a value for 25 rounds. It seemed important to handle the data in this manner since the 10 round groups were obtained in a period of about 5 minutes whereas the 15 round groups covered a period of time of several hours. However, it was concluded that the differences observed from these methods were insignificant and that the value which was obtained for all 25 rounds was most representative of that rifle.

It should be noted that although some rounds hit, the protective barricade, these misses were not excluded; hits were marked and by extrapolation were included in the dispersion calculations.

5. Limit Cycle Yaw (Limit Cycle Test)

The yaw was determined at each of the 5 photographic stations and then averaged to represent the value of the limit cycle yaw. It was assumed that all initial transient yaws had damped before the round had reached the stations, even for the closest distance used in this test series (175 meters). Data were obtained at three additional ranges: 253, 339, and 450 meters. Thirty rounds were fired from each of two rifles (one 1:12 in. twist and one 1:14 in. twist) at each range.

Velocity measurements were also recorded for each round. These values were adjusted since the guns were fired at different temperatures. The photographic stations were positioned in the Transonic Range, which is heated to about 70°F, but the guns were located outside the range except for the 175 meter range. The temperature at the time of firing varied from 35 to about 70°F. Corrections were made based on the muzzle velocity vs temperature data obtained at Eglin.

6. Physical Properties

When values of the physical properties are required to compute certain aerodynamic characteristics, it is highly desirable to use those properties which pertain to each round. Normally, for large shell, measurements are performed on the rounds before they are launched. In the case of deformable bullets, the characteristics are liable to change when the round is fired so that if prefiring measurement values are used, at least slightly incorrect results will be obtained. As a precaution, it was decided to obtain sample values of these physical measurements on projectiles which had sustained changes due to normal firing.

The EBL has undertaken the task to determine the changes in the bullet (particularly LC-SP-412) due to launch, but all of the results are not available for this report.

Past experience has indicated that in order to recover the bullet without damage with current recovery systems the bullet should have a velocity not much greater than about 365 m/s. Since measurements should be made on rounds which

have been launched at standard muzzle velocity,* the recovery system had to be placed about 600 meters from the gun.

A recovery system composed of foam rubber which was saturated with water was used. A depth of about 1.83 meters was required to stop the bullet. Ten rounds were fired from a 1:12 in. twist rifle, recovered, and measured. In addition, ten rounds were measured before launch and then recased and fired from the same gun, recovered and then remeasured. This procedure compares before and after measurements on the same round. These measurements involve moments of inertia, center of mass, length, and diameter. These data are available for this report but results of measurements made on the contour of the projectile before and after launch are not available at this time. There are two observations on shape changes that can be stated. First, the boattail appears to open up slightly, resembling a square base. Second, the ogive appears to cave in just ahead of the shoulder with a slight bulging of the ogive just ahead of the depression.

DISCUSSION OF RESULTS

The data resulting from the various tests are presented in tabulated form in the appendix in the following manner:

*Alternate methods of firing at reduced velocity may not produce full deformation, although the method is certainly an improvement over using unfired projectiles. In fact, all these differences may usually be irrelevant but it was felt necessary to conduct the test to be sure.

Table 1 Results of the Eglin Test
Table 2 Results of the Limit Cycle Yaw Test
Table 3 Dispersion (Eglin Test)
Table 4 Summary of Aerodynamic Coefficients
Table 5 Physical Properties
Table 6 Average Results

The remaining portion of this section will deal primarily with the average results presented in the tables. If differences between weapons are of interest, then the tables should be examined.

1. Velocity (Table 6)

The average muzzle velocity is plotted in Figure 5 as a function of temperature. The curves indicate that at 125°F the muzzle velocities of the 1:12 in. twist and 1:14 in. twist weapons are the same. As the temperature decreases, however, V_o for the 1:14 in. twist rifles decreases at a more rapid rate than does V_o for the 1:12 in. twist rifles until at -65°F they differ by about 21 m/s. In general, V_o decreases by about 84 m/s over the temperature range tested. Also included in Figure 5 are the velocities determined at 70 meters for the same conditions for which V_o was determined. These curves indicate that at the warm temperatures the loss in velocity for each weapon is about the same. At -65°F, however, rounds fired from the 1:14 in. twist rifles lose about 61 m/s more than those fired from 1:12 in. twist rifles. The reason for the increase in velocity loss is the considerable increase in yaw which adds to the drag.

2. Yaw (Table 6)

The average first maximum yaws for each rifle are plotted in Figure 6 as a function of tenperature. It can be seen that the initial yaws for the two rifles are about

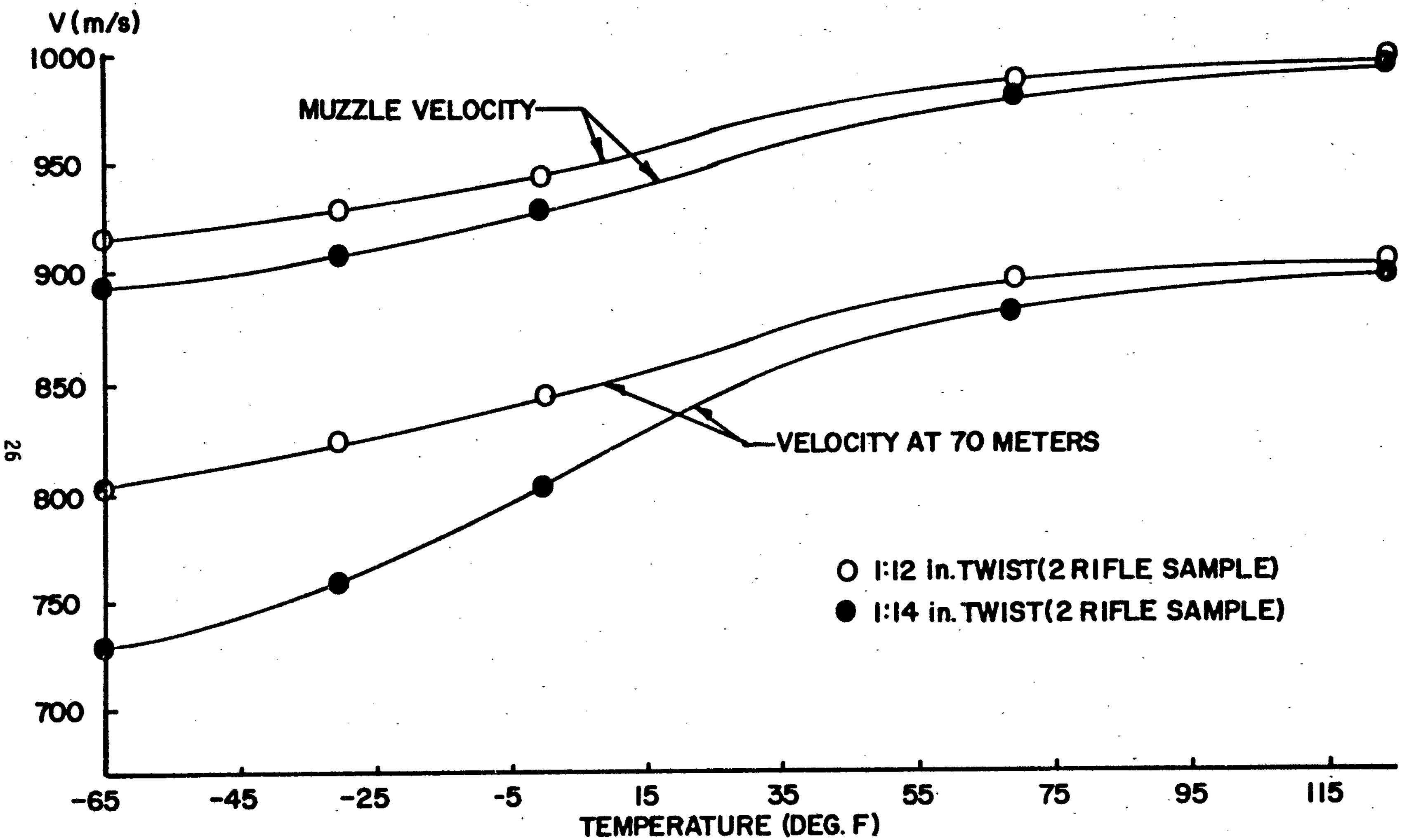

Figure 5. Average Velocity at the Muzzle and at 70 Meters vs Temperature

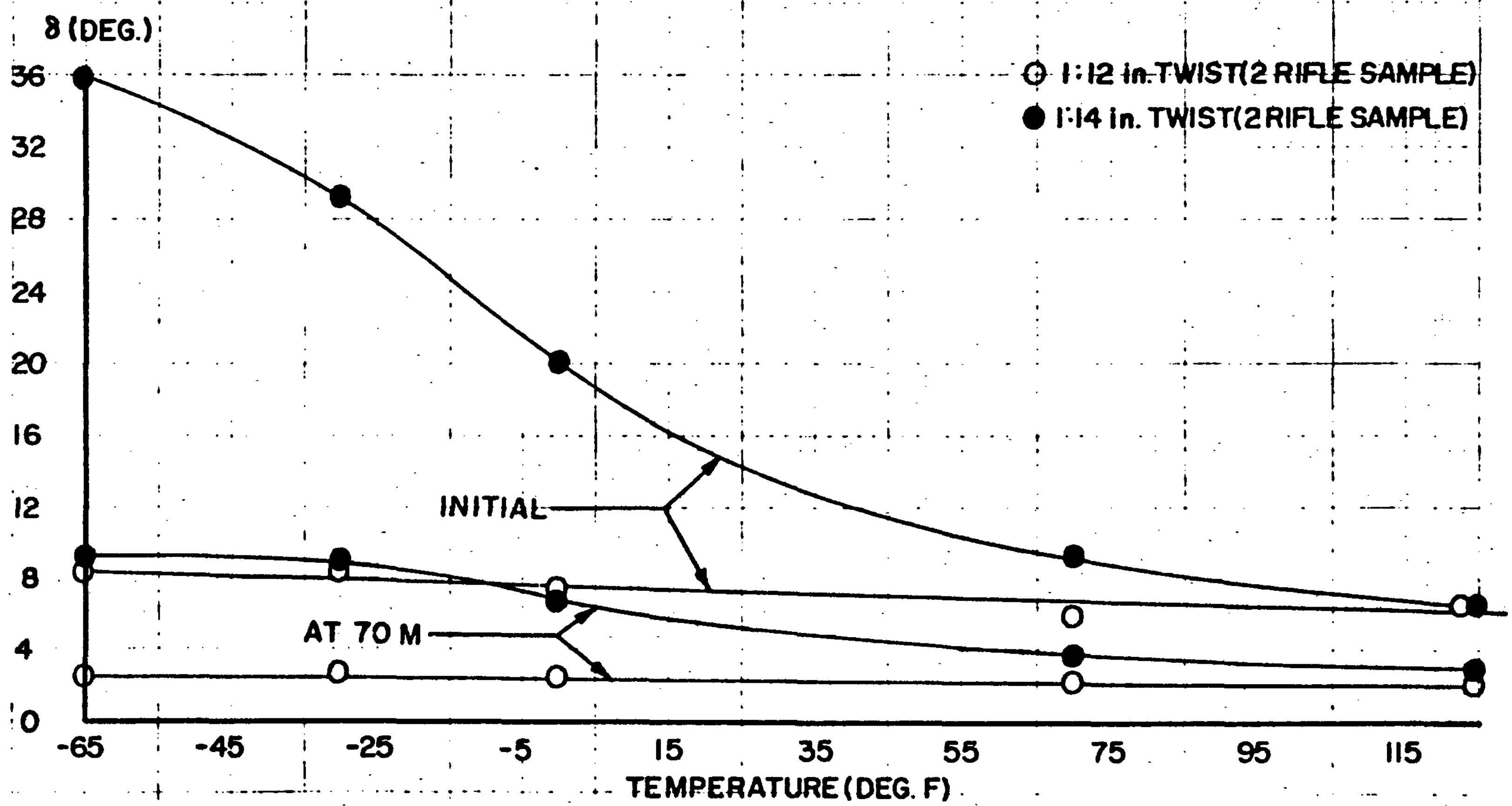

Figure 6. Average Maximum Yaw Near the Muzzle and at 70 Meters vs Temperature

the same at 125°F but differ considerably at -65°F. δ_o for the 1:12 in. twist rifle changes very little over the temperature range test while δ_o for the 1:14 in. twist rifle increases from about 6 degrees at 125°F to about 36 degrees at -65°F. Also included in Figure 6 are the maximum-yaw values determined at about 70 meters for each rifle. These values have about the same magnitude at the warmer temperatures but still differ significantly at -65°F -- about 3 degrees for the 1:12 in. twist rifles and about 9 degrees for the 1:14 in. twist rifles.

3. Stability Factor (Table 6)

The average stability factor, s, for each weapon is plotted in Figure 7 as a function of temperature. Stability factors were determined at all temperatures for the 1:12 in. twist rifles whereas s was determined at only 70 and 0 degrees for the 1:14 in. twist rifles. It would have been possible to obtain s at 125°F but insufficient test data at this temperature negated this determination. At 0°F and below, however, it is impossible to determine s accurately using linearized assumptions, but it can be adequately computed using data obtained at another temperature or by data obtained from another twist. Those portions of the curves shown as dotted lines were computed in this manner. The value of s determined at 125°F for the 1:12 in. twist rifle is slightly higher than is predicted. The reason for this difference is not apparent.

4. Dispersion (Table 6)

The dispersion, σ, is plotted as a function of temperature in Figure 8. Each point represents a weighted average combining the results of two 25 round groups (one group from each rifle). The value for each 25 round group was obtained using one center of impact. All rounds within

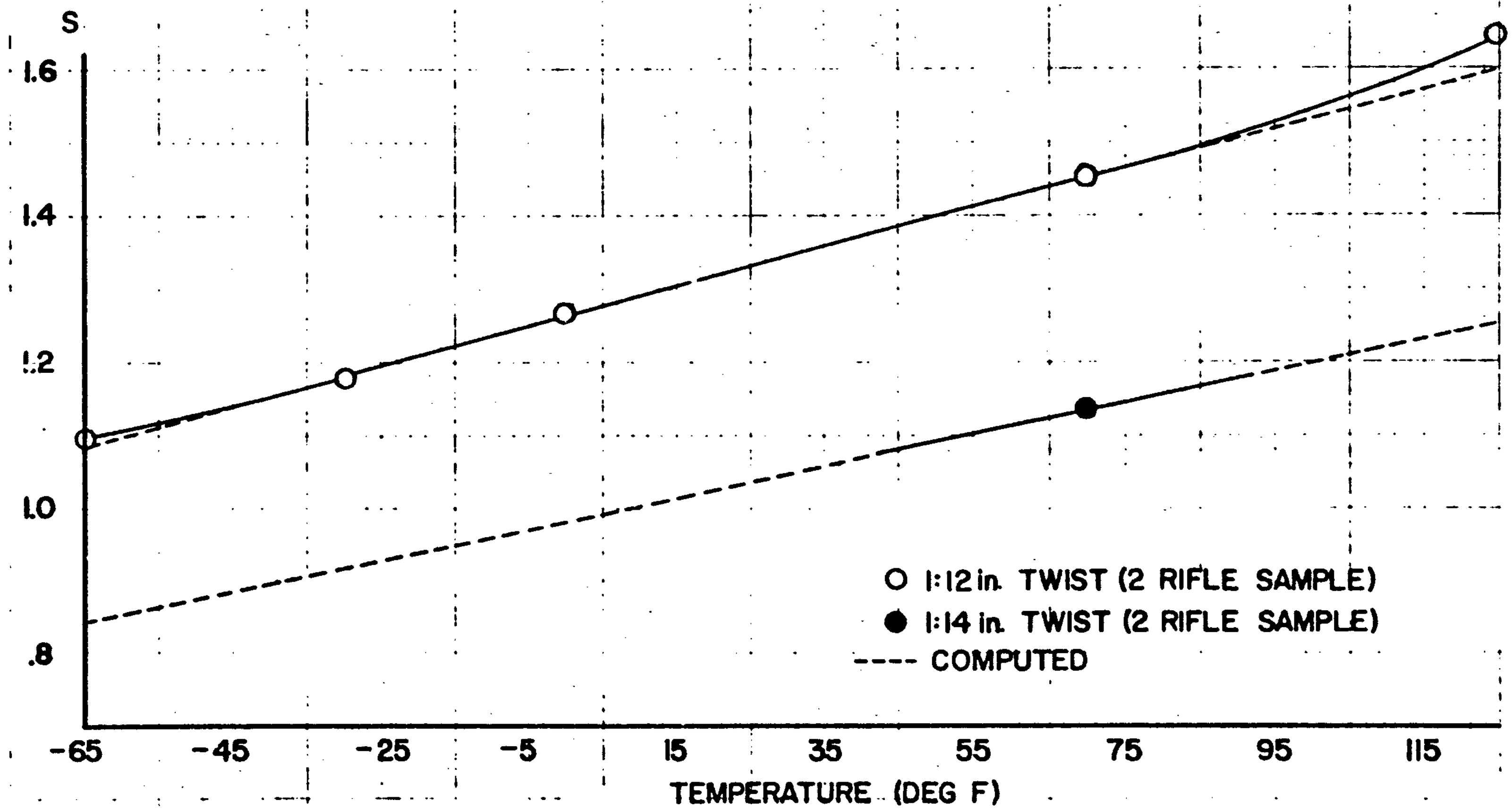

Figure 7. Average Initial Stability Factor (at 5 Meters) vs Temperature

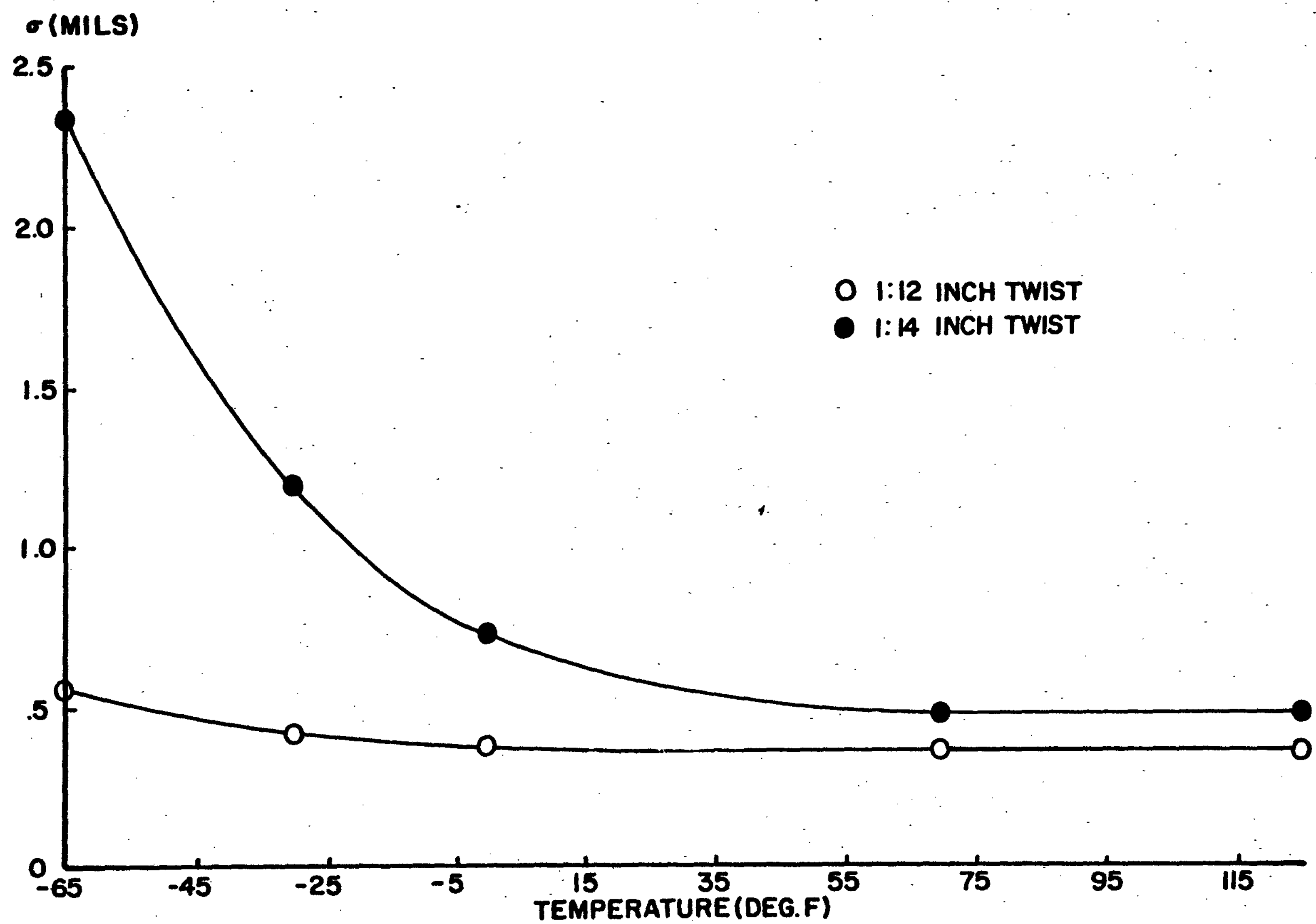

Figure 8. Dispersion vs Temperature
Weighted Average of Two 25-round Groups

a 25 round group were fired from a single gun location but 10 rounds were fired over a short period of time (approximately 5 minutes) while 15 rounds using photographic coverage required four hours or longer to fire. Hence, it is possible that differences in dispersion exist because of the time involved to complete each phase of the test. Figure 8 treats the data as though these differences are negligible. Individual results can be examined in Table 4.

Basically, the dispersion of both rifles is about the same for the warmer temperatures. At colder temperatures, σ begins to worsen for the 1:14 in. twist rifle until at -65°F it has become about 4 times greater than σ for the 1:12 in. twist rifle, which is relatively unchanged. The increase in dispersion begins when the stability factor nears 1. This occurs at about 40°F with the 1:14 in. twist rifle and at about -45°F with the 1:12 in. twist rifle.

5. Limit Cycle (Table 2)

The distribution of the limit cycle yaw is shown as a function of range in Figure 9 for the 1:12 in. twist rifle and Figure 10 for the 1:14 in. twist rifle. It was intended that the data be obtained at 70°F but the temperature could not be controlled for the three longer ranges since the guns were outside the Transonic Range building. The temperatures outside of the building varied from 35 to 70°F. At the 175 meter range, the guns were mounted inside the building which is normally temperature-controlled to about 70°F. The effect of colder temperatures is a slight decrease in muzzle velocity from both rifles and in the case of the 1:14 in. twist rifle, a slight increase in initial yaw (not measured in this test). It is felt that the magnitude of the observed yaw at the photographic stations was not significantly changed by the

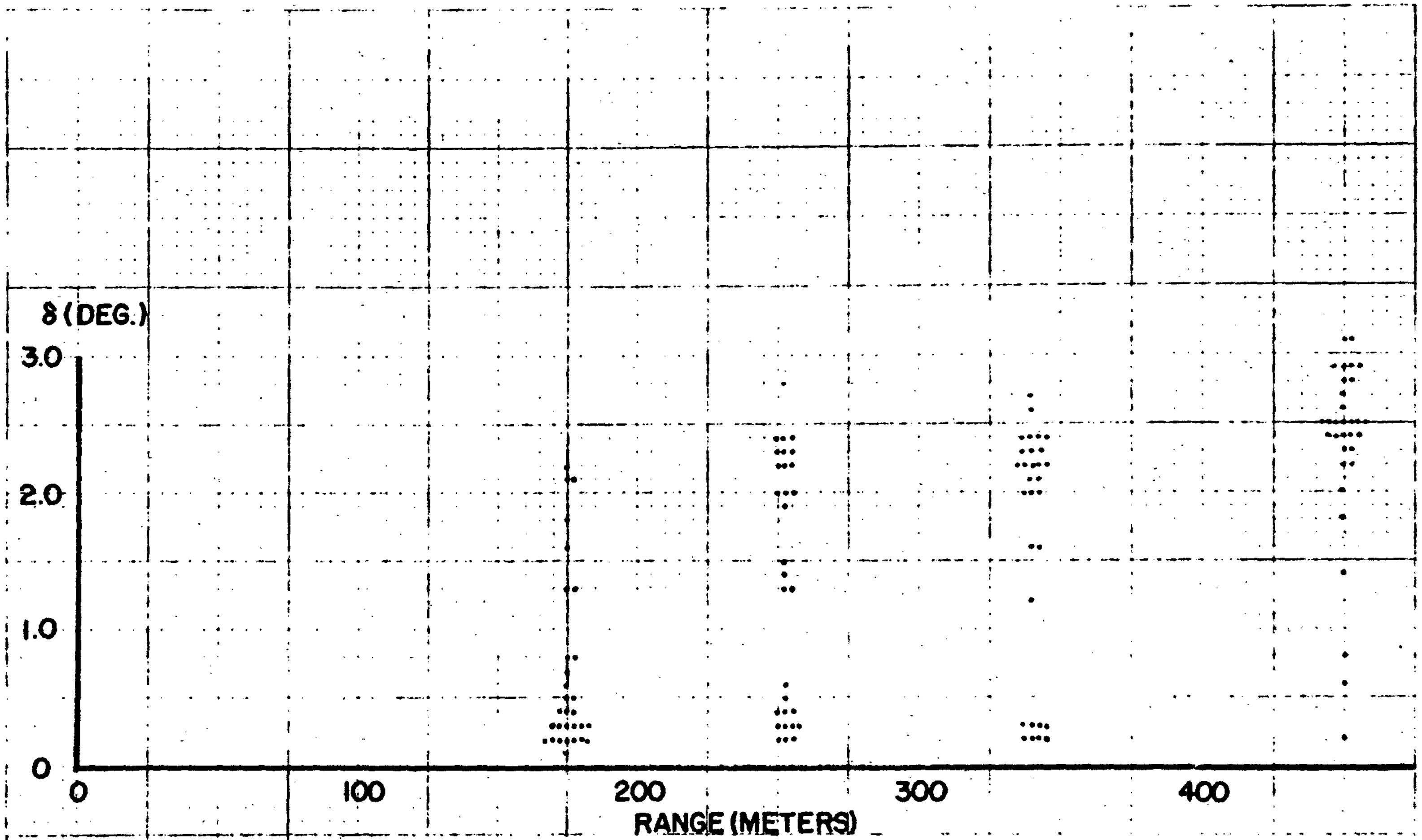

Figure 9. Distribution of Limit Cycle Yaw vs Distance
1:12 in. Twist (SN 023199) 70^{0}F

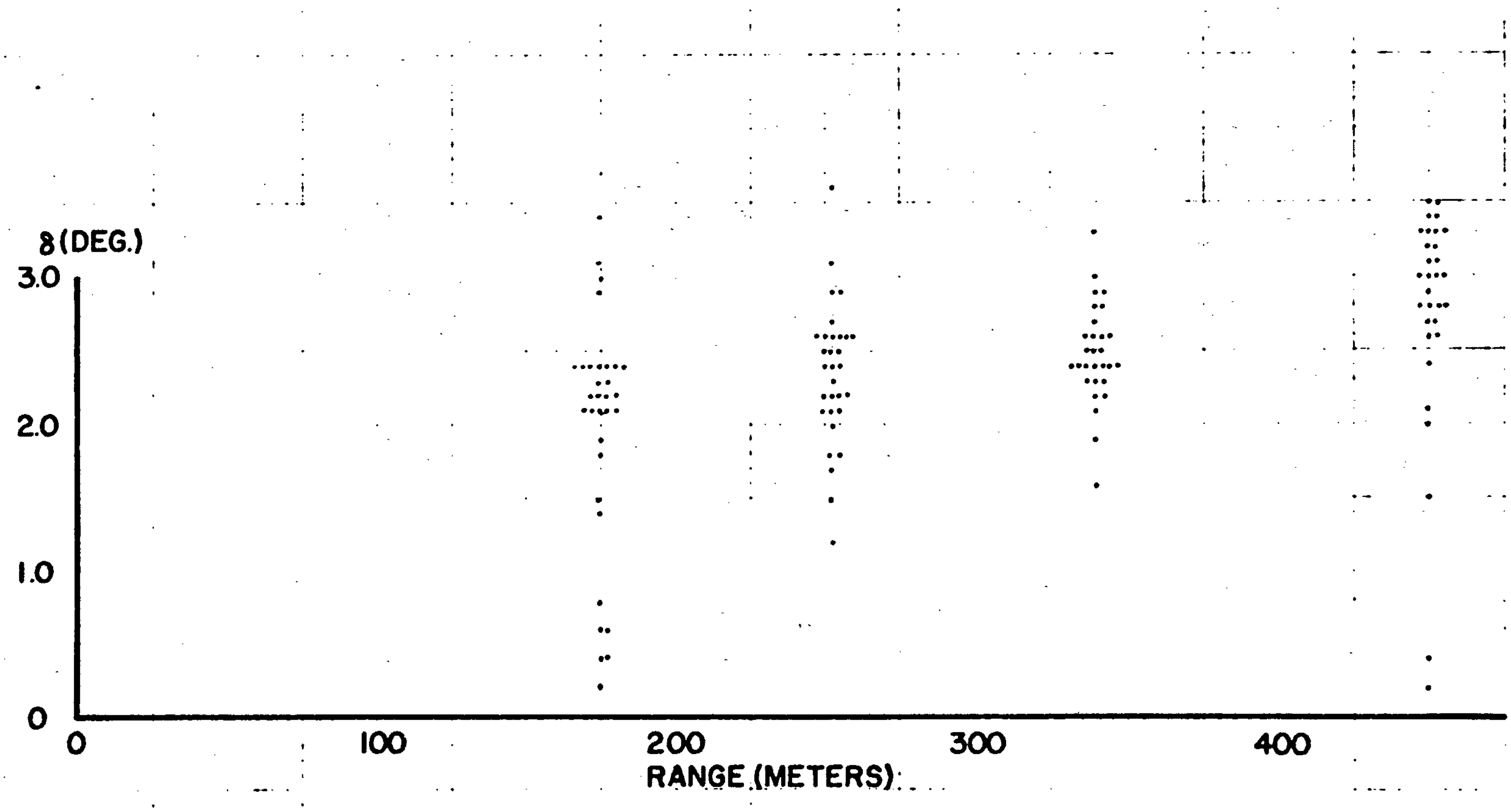

Figure 10. Distribution of Limit Cycle Yaw vs Distance
1:14 in. Twist (SN 789076) 70°F

increased initial yaw, because all rounds, regardless of distance fired, traveled through about 200 meters of 70°F air in the Transonic Range before being photographed. Recordings obtained for the 1:14 in. twist rifle and for some of the 1:12 in. twist rifle rounds are for velocities which are slightly lower than if the rounds had been launched at 70°F.

It should be noted that at 450 meters, only about 50 percent of the rounds launched from the 1:14 in. twist rifle negotiated the protective barricade. There are three equally important reasons for this inaccuracy. First, the 1:14 in. twist rifle normally has slightly poorer dispersion than the 1:12 in. twist rifle under the same conditions. Second, the dispersion of the 1:14 in. twist rifle increases slightly because of higher initial yaws which the 1:12 in. twist rifle did not experience. Third, the rounds launched from both twist rifles experienced a strong cross wind (about 150 meters before entering still air) which appeared to have a significant bearing on the rifles' accuracy.

The curves in Figures 9 and 10 indicate the same approximate trends. The major difference occurs at 175 meters where the yaw from the 1:12 in. twist rifle is considerably less than from the 1:14 in. twist weapon. Two reasons are apparent for this difference. First, larger initial yaws from the 1:14 in. twist rifle will cause slightly higher yaws at this range. Second, because of these higher initial yaws, slightly more velocity will be lost, with the same effect as obtaining 1:14 in. twist data further downrange. This is apparent upon examination of the data as a function of velocity instead of range. Since the limit cycle yaw is increasing quite rapidly between 175 and 250 meters, a decrease of about 23 m/s in

the velocity of the projectile should significantly increase the magnitude of the limit cycle.

After about 175 meters of travel, little additional difference in velocity should be expected. The magnitude of yaw beyond 175 meters appears to be slightly higher for the 1:14 in. twist rifle with a slight upward trend occurring at 450 meters. If the data are examined as a function of velocity, this upward trend occurs for both twist rifles but is slightly more apparent with the 1:14 in. twist weapon, mainly because the projectile has slightly less velocity at 450 meters.

The probable reason why the upward trend occurs from either weapon is the fact that the projectile is rapidly approaching the transonic region. Although no data on this projectile are available to substantiate this conclusion, other data do exist on a prototype model (unpublished) and on the M-80 ball projectile[6] which strongly suggest that limit cycles larger than two or three degrees will exist below Mach 1. Therefore, it is quite conceivable that the M-193 bullet will begin to respond to this effect by 450 meters.

Figure 11 is a plot of the velocity of the projectile as a function of range and twist. All velocity values have been adjusted to the expected value at 70°F. The curves are a compilation of data obtained at Eglin and at the Aerodynamics and Transonic Ranges.

6. Physical Properties (Table 5)

Only a limited amount of work has currently been performed on determining the physical changes in a bullet caused by forces at launch. Bullets have been measured prior to and after launch; the results of these measurements can be compared in Table ~~5~~.

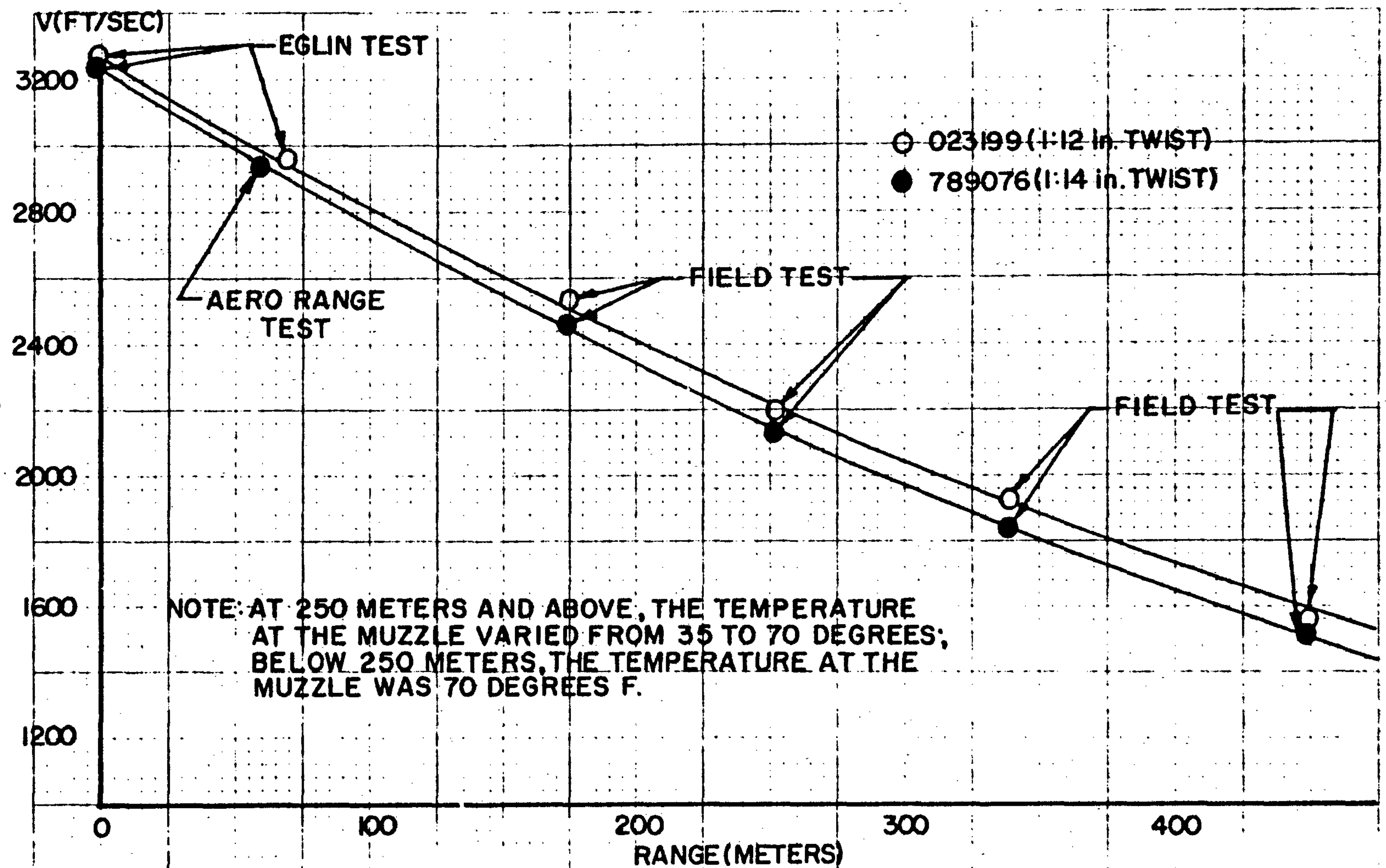

Figure 11. Velocities Measured at Nominally Ambient Temperatures Corrected to 70° F vs Distance

The measurements that have been conducted indicate the variations in the physical parameters and the changes in these parameters due to launch. While most of the changes or variations are small (on the order of 2 or 3 per cent or less), the resultant error of combinations of these parameters, such as used for spin calculations, can be considerably larger.

Some of the more subtle changes which occur during launch are those which physically change the shape of bullets and are much more difficult to measure: such changes as loss of copper, damage to the jacket, distortion of the boattail section, etc. It is sometimes difficult to observe these changes with the naked eye but they can often be seen in the shadowgraphs of the projectile in flight.

Several enlarged shadowgraphs are presented (Figures 12 through 18). The pictures encompass firings at various conditions. If the reader will note that any sudden change in the contour of the projectile will produce a shock wave, it will become immediately obvious that the projectile has changed considerably during launch. A brief description of each figure is given below. While it is left to the reader to decide as to the degree of damage which may be observed in the figures, his attention is invited to the flow about the projectile as a function of yaw. It should be noted that as the yaw increases the prediction of certain aerodynamic characteristics becomes more difficult.

Figure 12: A round fired at -65°F from a 1:14 in. twist rifle. The angle of yaw is about 30 degrees. Note that the flow has leeward separation at the nose.

Figure 13: A round fired at -65°F from a 1:14 in. twist rifle. The angle of yaw is about 25 degrees. Note that the flow separation point has moved rearward to about the position of the shoulder.

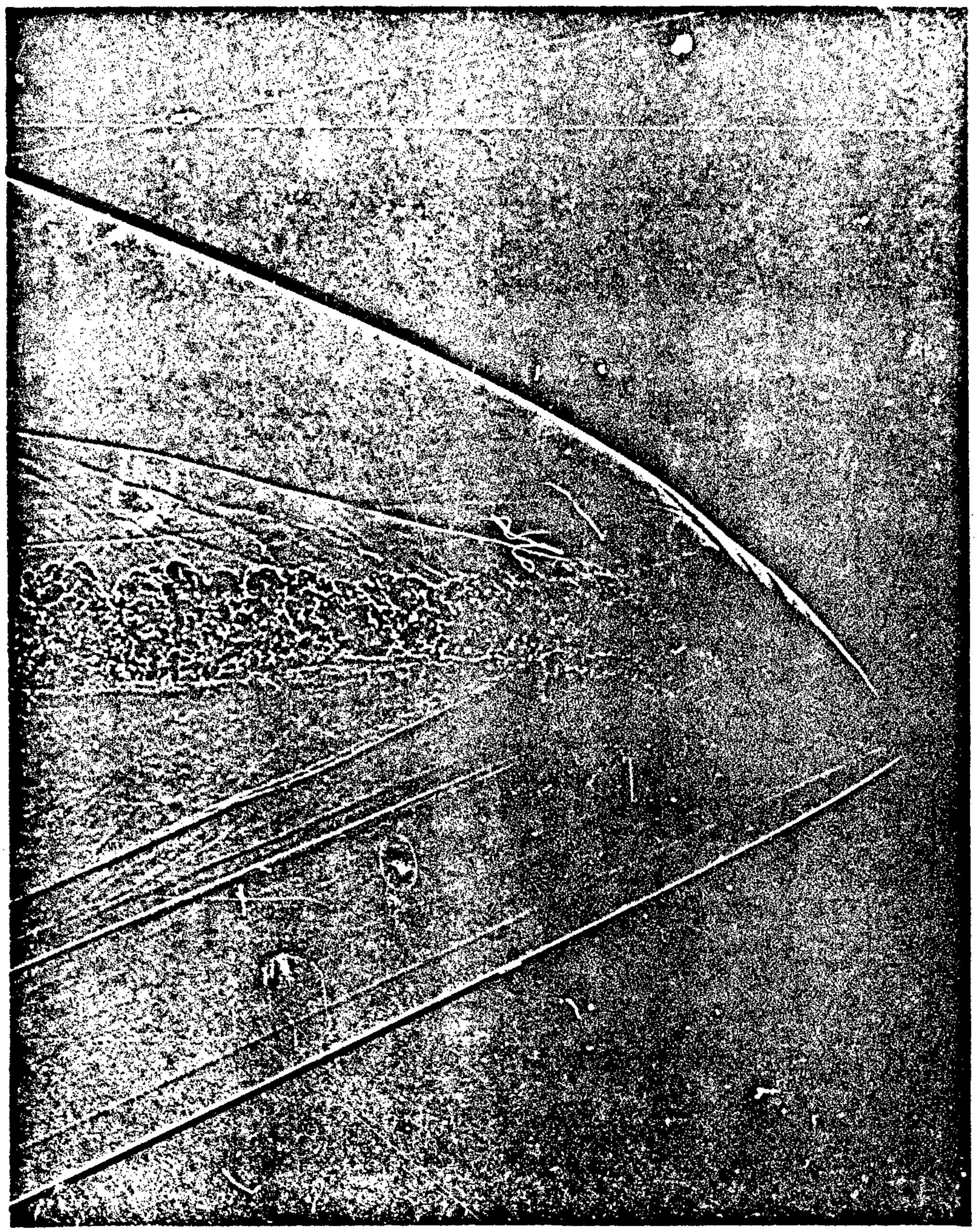

Figure 12. M-193 at - 65^{o}F
V = 870 m/s δ = 30^{o}

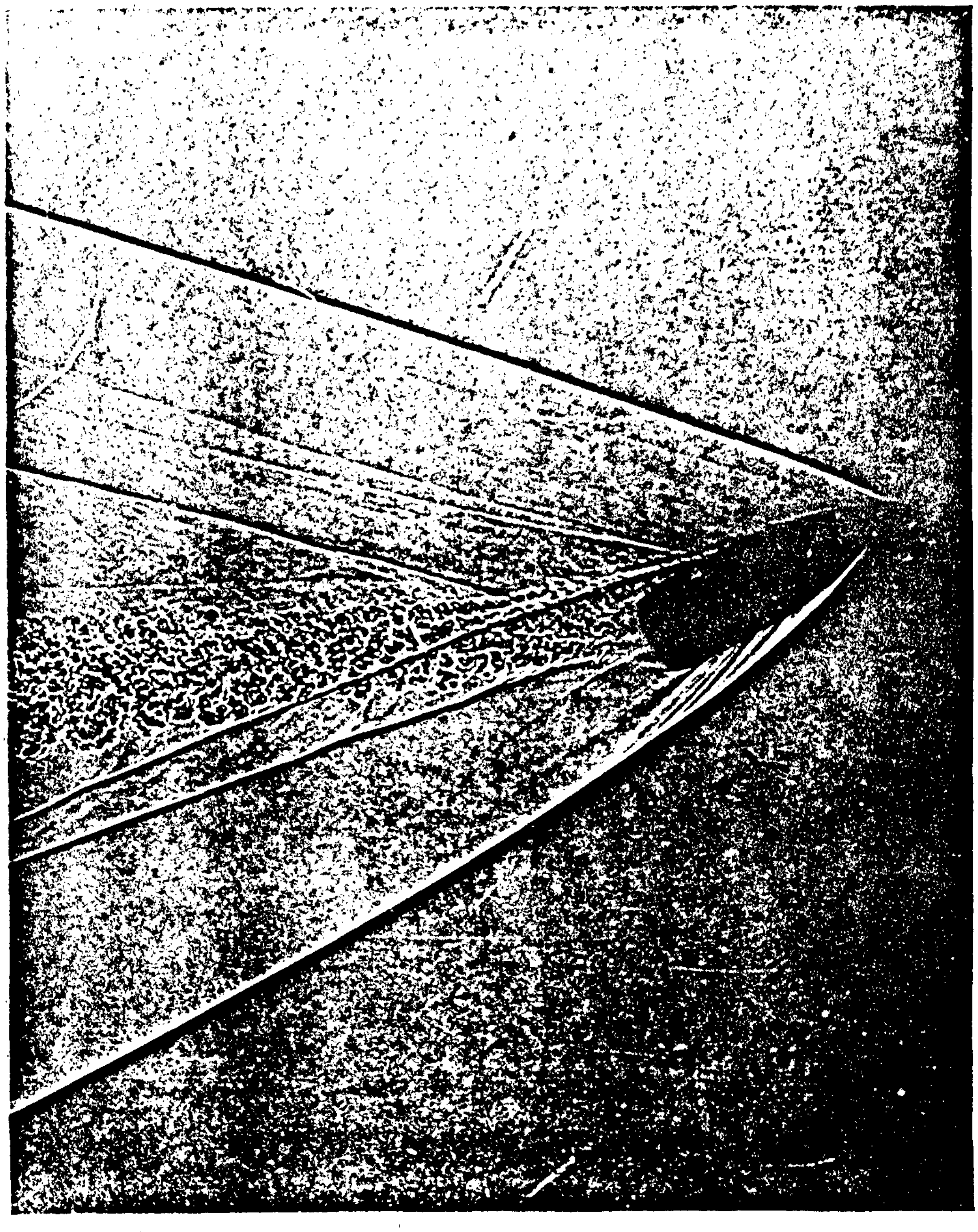

Figure 13. M-193 at $-65^{o}F$
$V = 925$ m/s $\delta = 25^{o}$

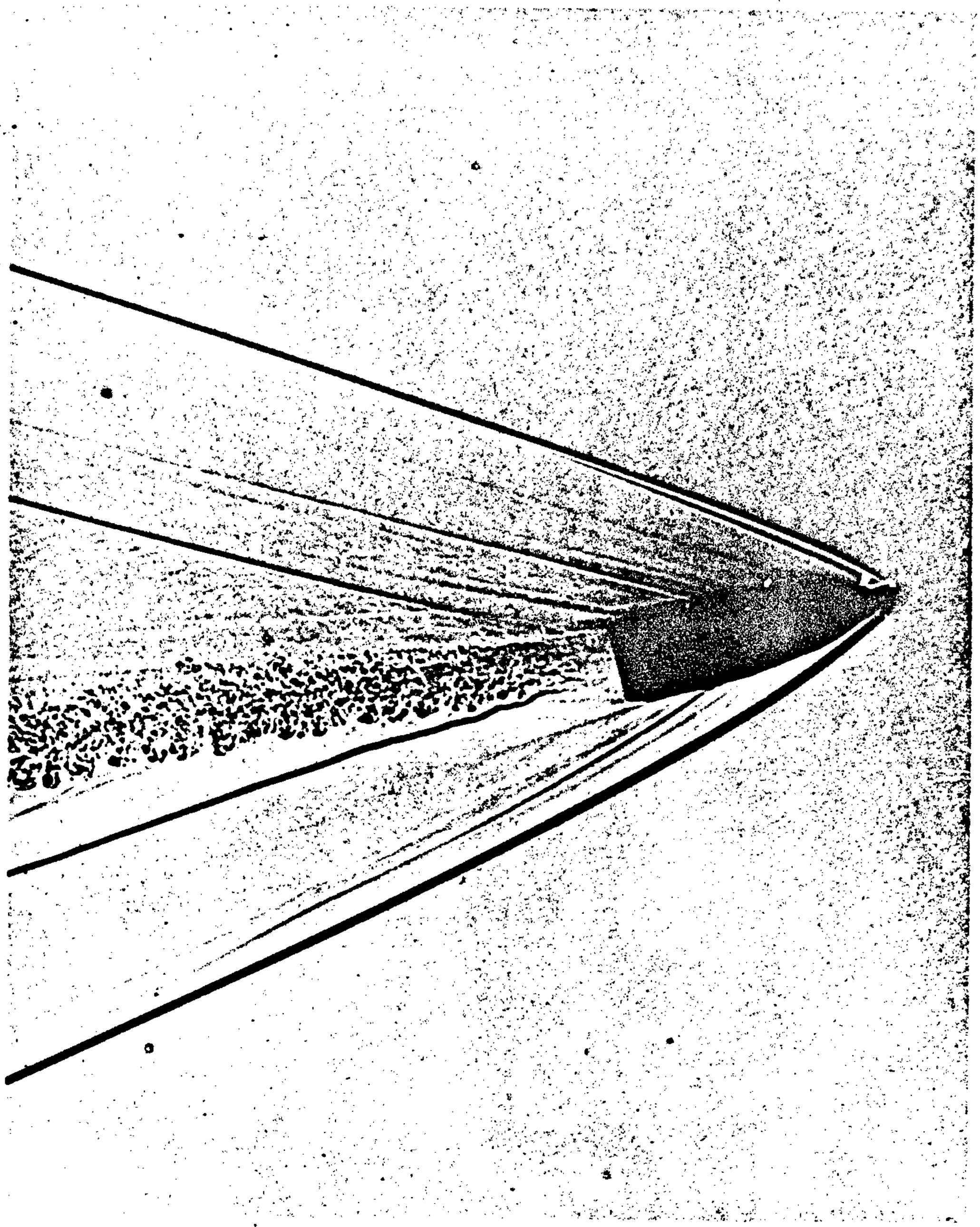

Figure 14. M-193 at $-65^{0}F$
$V = 910$ m/s $\delta = 10^{0}$

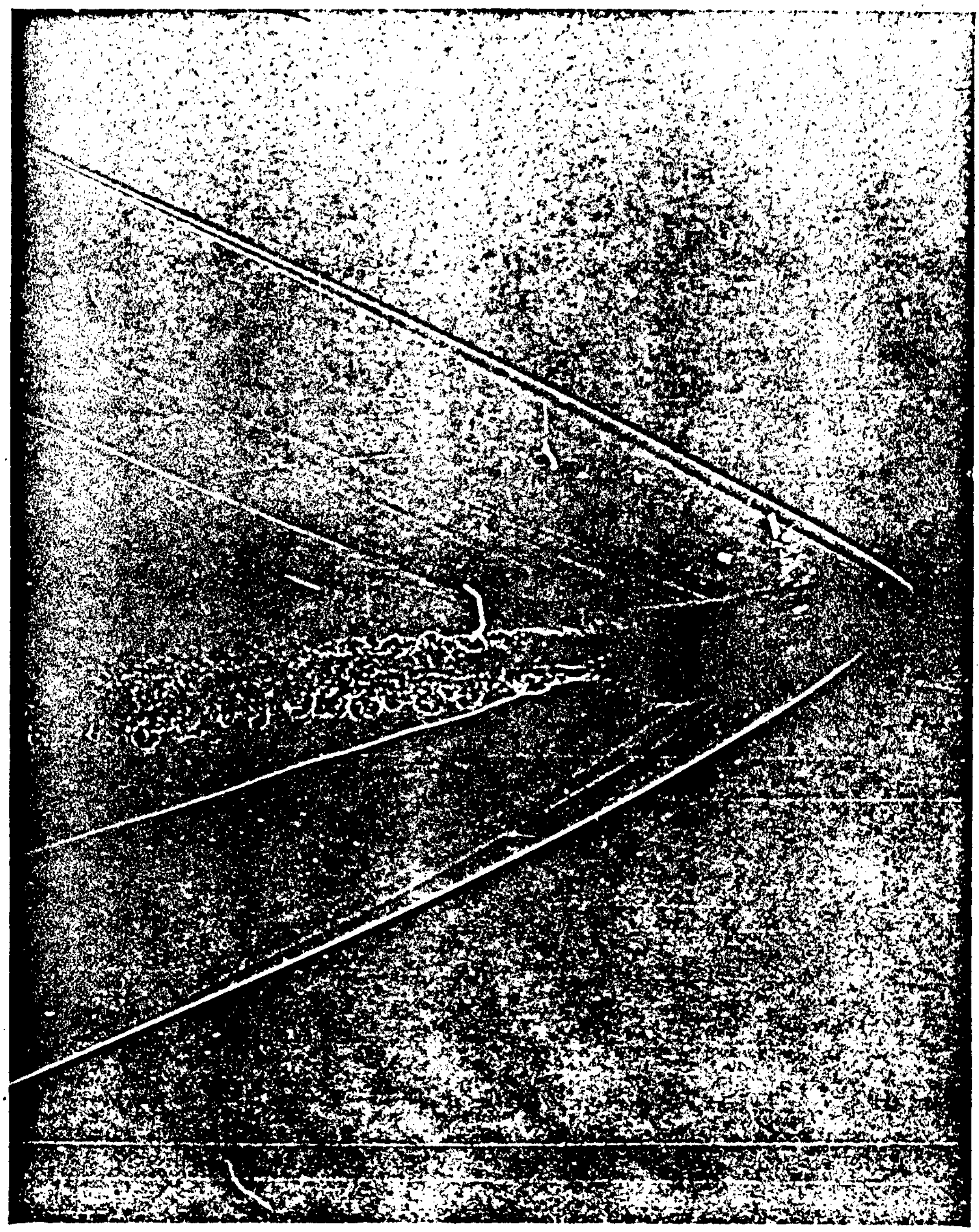

Figure 15. M-193 at 125^{o}F
$V = 965$ m/s $\delta = 10^{o}$

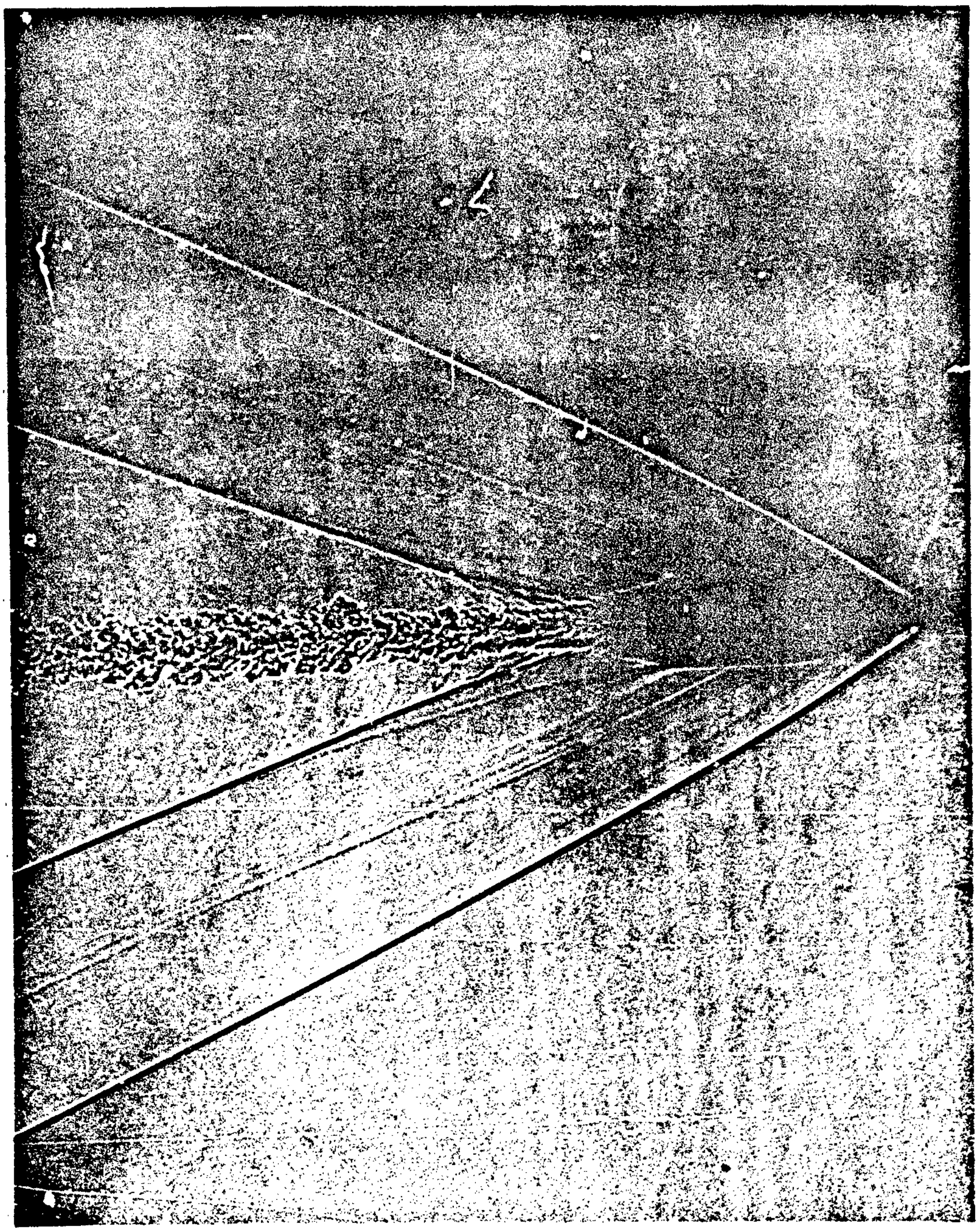

Figure 16. M-193 at $125^{o}F$
$V = 995$ m/s $\delta = 1^{o}$

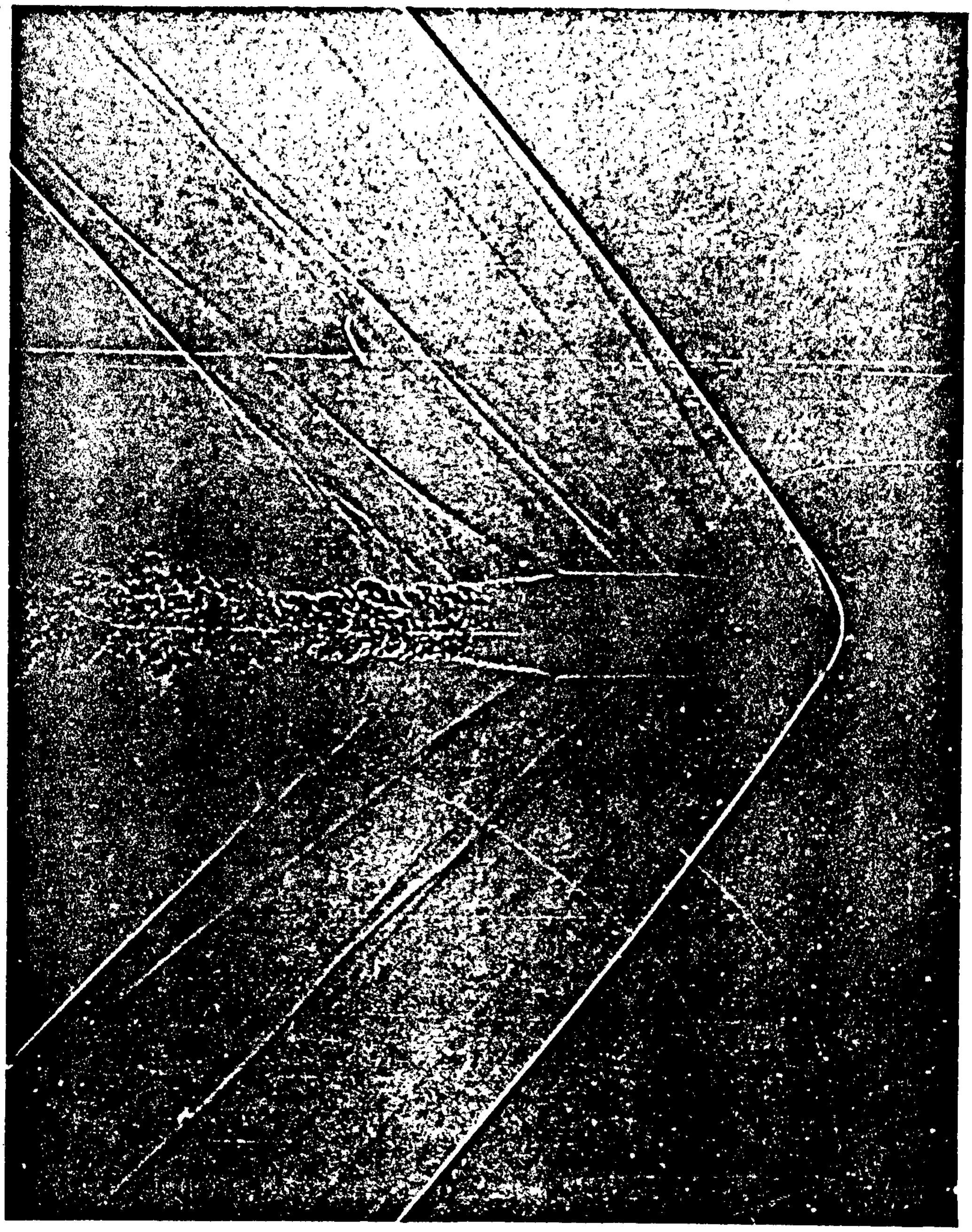

Figure 17. M-193 at 70^{o}F
V = 472 m/s δ = 2.5^{o}

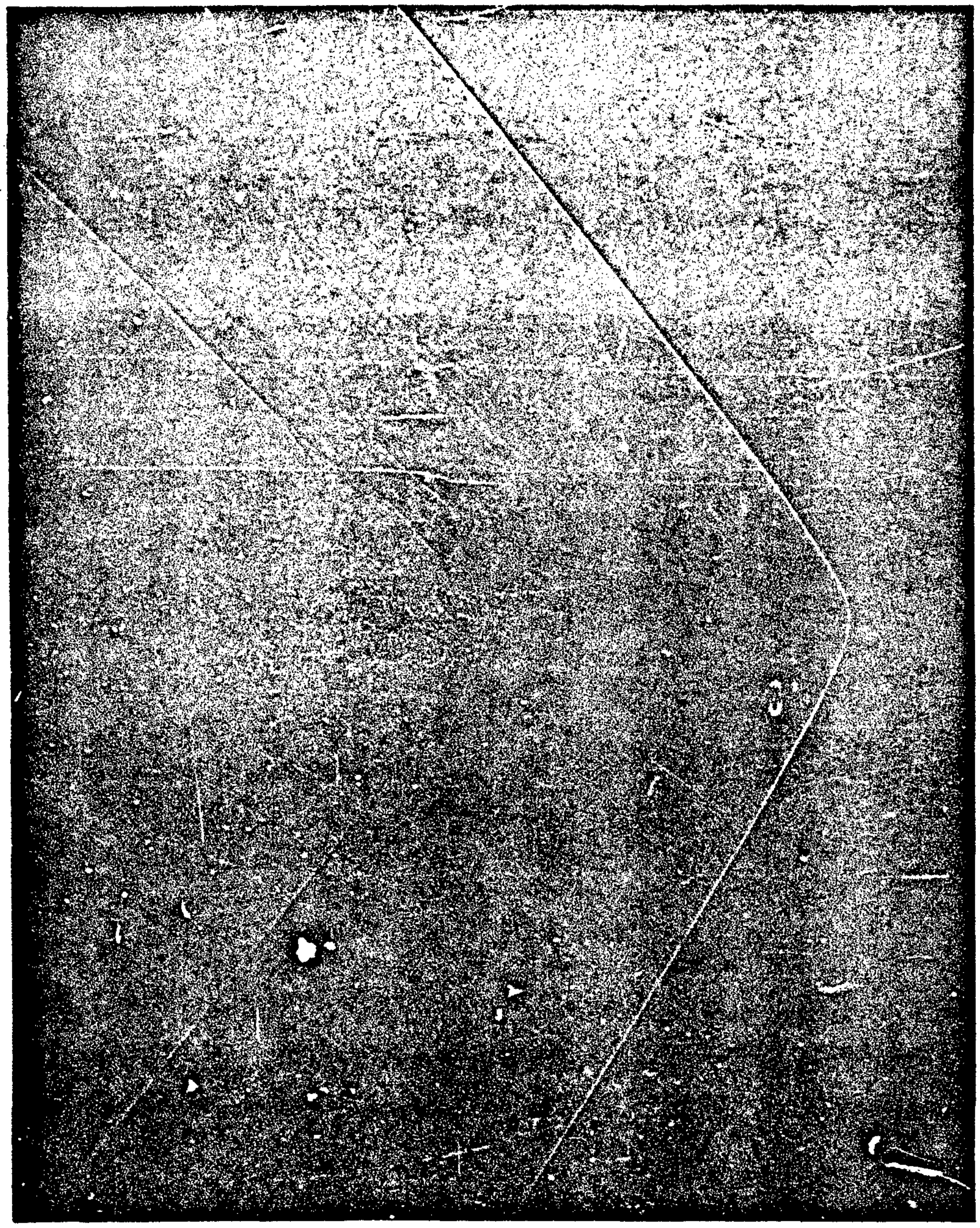

Figure 18. M-193 at 70^{0}F
V = 455 m/s δ = 2.5^{0}

Figure 14: A round fired at $-65^{\circ}F$ from a 1:12 in. twist rifle. The angle of yaw is about 10 degrees and the flow now separates at about the position of the crimping groove.

Figure 15: A round fired at $125^{\circ}F$ from a 1:14 in. twist rifle. The yaw angle and flow separation position are about the same as in Figure 14.

Figure 16: A round fired at $125^{\circ}F$ from a 1:14 in. twist rifle. The angle of yaw is less than one degree. The flow has turned the corner of the boattail.

Figure 17 and 18: Rounds photographed at about $70^{\circ}F$ at a velocity of about 457 m/s. Both rounds were fired from a 1:14 in. twist rifle. The rounds have limit cycle yaws of about 2.5 degrees.

7. Twist Determinations (Table 1)

Computations of the rifle twists have been made for each round fired at Eglin. A knowledge of the yawing motion and the moments of inertia are required to compute these values. Since it was not possible to obtain moments of inertia for each round fired, the average value obtained from recovered rounds was used for all rounds; hence, the variations in the twist values given in Table 1 are only true if the values of the average moments of inertia are precisely those ascribed to the bullet, which is not the case. On the other hand, averaging several twist values should yield a representative value of the spin imparted to the bullet. The nature of the yawing motion of this projectile is such that the spin will become less well determined as the stability factor approaches one.

The average values of twist computed in this manner are 1:11.9 in. for the 1:12 in. twist rifle and 1:13.5 for the 1:14 in. twist rifle. These numbers are evaluated at a

point 4.57 meters in front of the muzzle and should be increased by about .08 in. to give muzzle values. Agreement is quite good for the 1:12 in. twist computations whereas computations for the 1:14 in. twist rifle indicate that the rifle imparted more spin to the bullet than the rifling had. The difference is on the order of 2 or 3% and could easily be accounted for by the reasons previously mentioned.

In order to determine conclusively the spin imparted to the bullet, measurements of the spin of the bullet in flight should be made and extrapolated to the muzzle. This can be done to an accuracy of less than .1% by fitting the projectile with pins in the base before launch and measuring the orientation of these pins as a function of range. Five rounds have been tested from one rifle in this manner but the results are not available at this time.

The D&PS at Aberdeen measured the twist of rifling of 120 rifles (60 1:12 in. twist and 60 1:14 in. twist rifles). Measurements were recorded at 1 inch intervals along the tube. The method and results of these measurements are given in Reference 7. In addition, the four prime rifles used in the BRL tests were measured; the results are presented in Figures 19 and 20. It is noted that the measured values do not form a smooth curve so it is difficult to determine the precise twist at the time the bullet becomes disengaged from the rifling.

CONCLUSIONS

1. The M-193 projectile when launched from a 1 in 12 inch twist tube is gyroscopically stable at the atmospheric densities consistent with military test temperatures ranging from 125°F to -65°F.

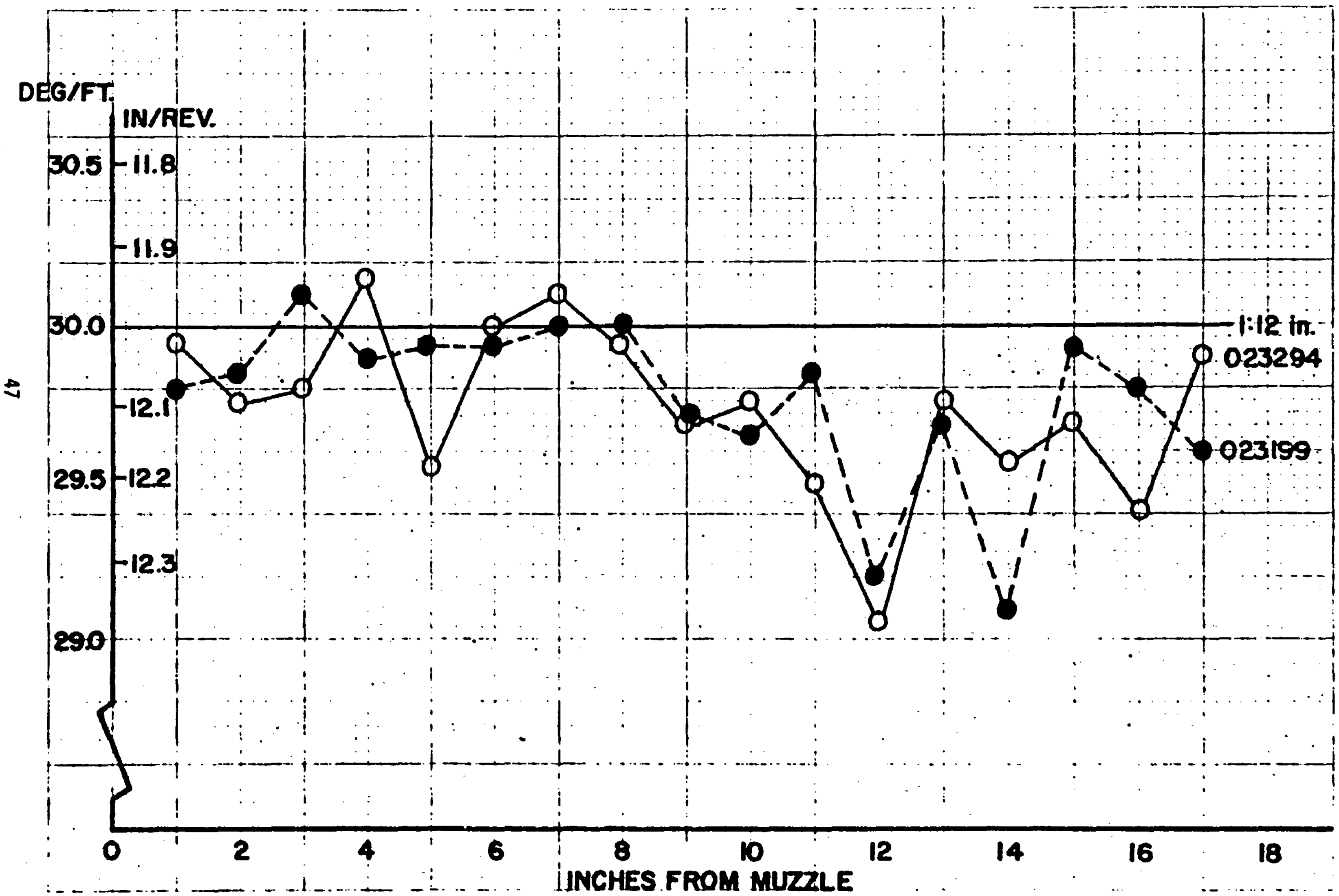

Figure 19. Twist Rate Eglin Test Guns (1/12)
(Based on Measurements at One Inch Intervals)

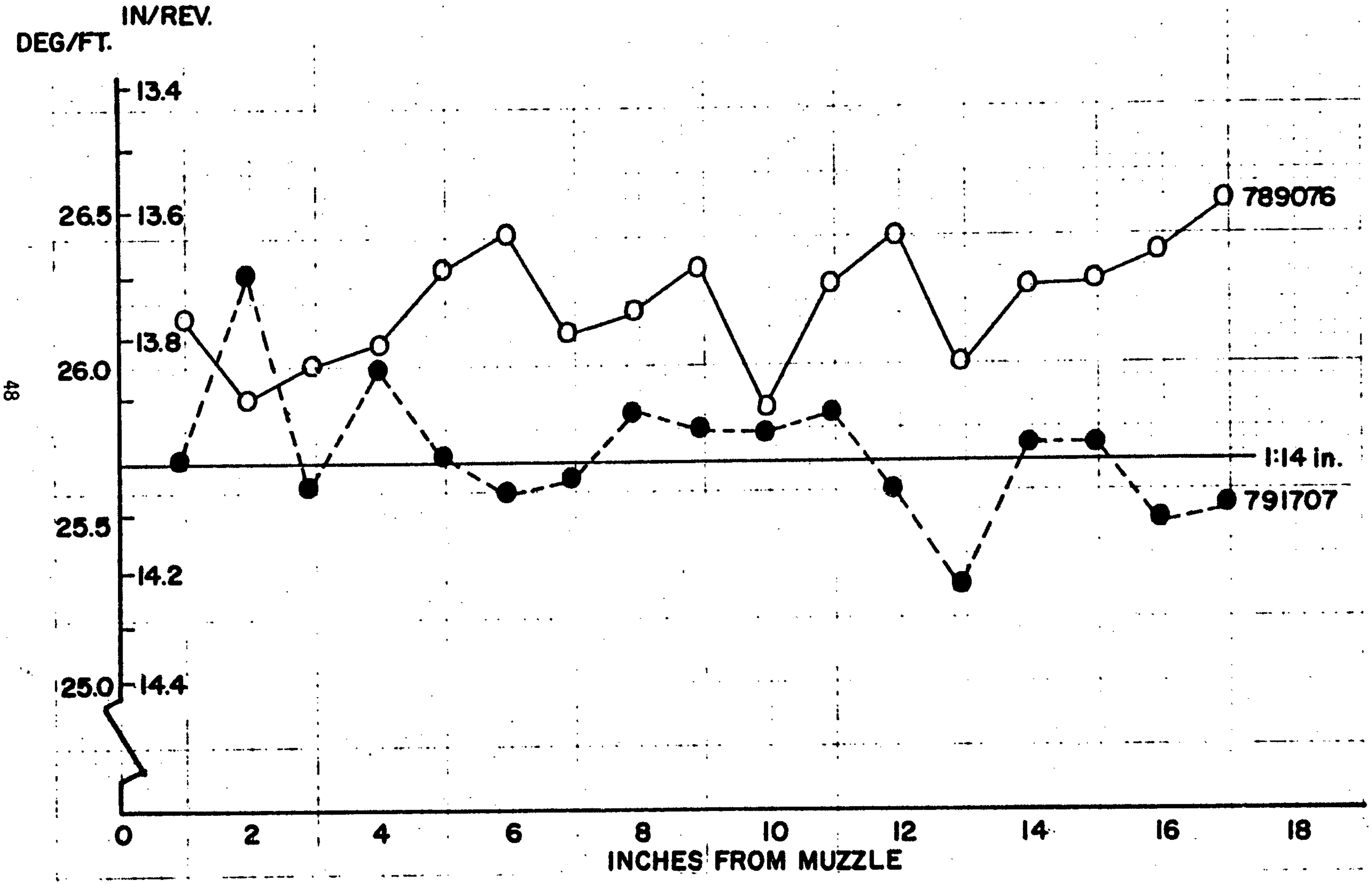

Figure 20. Twist Rate Eglin Test Guns (1/14)
(Based on Measurements at One Inch Intervals)

2. The M-193 projectile when launched from a 1 in 14 inch twist tube is gyroscopically unstable at the atmospheric densities consistent with military test temperatures of below about 0°F.

3. Both twist weapons produce about the same initial maximum yaw at normal air density and below (yaw from the 1:14 in. twist tube is slightly larger). At the high density condition (-65°F) the 1:14 in. twist weapon produces about 36° of yaw as compared to about 8° yaw from the 1:12 in. twist rifle.

4. The dispersion is about the same for each twist at normal air densities (the 1:14 in. twist being slightly larger) with the dispersion of the 1:14 in. twist weapon being considerably worse at the high density cold temperatures. At the -65°F test point, these values are about 2.4 mils for the 1:14 in. twist as compared to about .6 mils for the 1:12 in. twist rifle.

5. Terminal yaw of the M-193 projectile when launched from either weapon varies from nearly zero yaw to about 3.5 degrees. Generally, the yaw obtained from the 1:14 in. twist rifle tested was slightly larger than that from the 1:12 in. twist rifle for the same range.

6. The sample of the current M-193 projectile production used in the test receives a certain amount of damage during launch. The boattail and ogive sections appear to be the areas most affected.

7. In-bore and aerodynamic spin measurements indicated that the rifles with the 1:14 in. twist had twists which were faster than 1:14 (on the order of 1:13.8 inches) while no significant difference was observed in 1:12 in. twist rifles.

REFERENCES

1. Brochure, Climatic Laboratory Facilities Air Force Systems Command, Eglin Air Force Base, Florida.

2. W. F. Braun, "The Free Flight Aerodynamics Range", Ballistic Research Laboratories Report No. 1048, July 1958, AD 202249.

3. W. K. Rogers, Jr., "The Transonic Free Flight Range", Ballistic Research Laboratories Report No. 1044, June 1958, AD 200177.

4. C. H. Murphy, "Free Flight Motion of Symmetric Missiles", Ballistic Research Laboratories Report No. 1216, July 1963, AD 442757.

5. M. J. Piddington, "The Aerodynamic Properties of a Caliber .223 Remington Bullet Used in M16 (AR-15) Rifle", Ballistic Research Laboratories Memorandum Report No. 1758, June 1966, AD 489960.

6. M. J. Piddington, "Aerodynamic Characteristics of the 7.62mm NATO Ammunition M-59, M-80, M-61, M-62", Ballistic Research Laboratories Memorandum Report No. 1833, March 1967, AD 815788.

7. H. M. Jamison, "Test of 120 Rifles - 5.56mm M16A1. 60 Rifles with a Basic Twist of 1:12.0 in. and 60 Rifles with a Basic Twist of 1:14.0 in.", Physical Test Laboratory Report No. 68-8-15.

APPENDIX

TABLES

BLANK PAGE

TABLE 1A EGLIN TEST RESULTS

SN 023294 (1:12 in. Twist)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
208	- 65	2892	2507	.401	14.4	4.1	12.1	1.51	1.12
209	"	3068	2688	.383	8.4	3.0	12.0	1.57	1.09
210	"	2893	2500	.431	18.7	5.0	12.0	1.57	1.10
211	"	2991	2618	.370	13.6	3.7	11.9	1.62	1.08
212	"	3002	2608	.414	16.7	4.5	11.9	1.53	1.13
213	"	2968	2615	.335	7.3	2.0	12.1	1.56	1.07
214	"	2998	2620	.369	12.2	3.8	11.6	1.61	1.14
215	"	3205	2831	.337	5.5	--	11.6	1.68	1.09
216	"	2969	2597	.395	9.1	2.9	11.6	1.66	1.09
217	"	2818	2460	.388	7.2	2.7	12.1	1.60	1.04
218	"	2934	2568	.376	7.6	2.5	11.9	1.63	1.06
219	"	2953	2572	.398	14.7	3.9	11.9	1.61	1.07
220	"	2950	2567	.402	10.1	3.7	11.9	1.58	1.09
221	"	3034	2678	.319	5.4	2.1	11.8	1.65	1.08
222	"	3073	2692	.355	9.5	2.7	11.8	1.54	1.14
Avg	- 65	2983	2606	.378	10.7	3.3	11.9	1.60	1.09

TABLE 1A EGLIN TEST RESULTS

SN 023294 (1:12 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
156	- 30	3115	2780	.318	5.6	1.9	12.1	1.61	1.13
157	"	2951	2614	.343	6.5	2.0	11.5	1.63	1.24
158	"	2990	2622	.396	13.1	4.2	--	--	--
159	"	3056	2710	.347	9.4	2.5	12.0	1.56	1.18
160	"	3075	2736	.323	5.1	1.7	11.8	1.60	1.20
161	"	2973	2650	.314	2.2	.6	12.1	1.59	1.13
162	"	3045	2707	.329	6.3	1.9	--	--	--
163	"	2923	2581	.371	12.3	3.5	12.1	1.60	1.14
164	"	2996	2648	.361	9.6	3.1	12.1	1.48	1.24
165	"	3082	2737	.339	7.7	2.7	11.7	1.65	1.18
166	"	3040	2696	.339	7.3	2.7	12.1	1.58	1.15
167	"	2974	2630	.355	9.9	3.7	12.1	1.60	1.13
168	"	2949	2614	.337	9.4	3.2	12.0	1.57	1.17
169	"	3070	2697	.408	17.7	4.6	12.0	1.52	1.22
170	"	2928	2584	.370	11.2	3.4	11.9	1.55	1.21
Avg	- 30	3011	2667	.350	8.9	2.9	12.0	1.58	1.18

TABLE 1A EGLIN TEST RESULTS

SN 023294 (1:12 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
261	0	3078	2762	.311	3.2	2.7	12.0	1.64	1.21
262	"	3073	2745	.338	8.1	3.4	12.0	1.58	1.25
263	"	2963	2603	.436	17.6	5.1	12.1	1.45	1.35
264	"	2995	2658	.374	13.3	4.7	12.1	1.57	1.24
265	"	2987	2668	.341	8.6	3.2	12.2	1.62	1.18
266	"	2981	2664	.329	1.7	.8	12.0	1.55	1.27
267	"	3031	--	--	9.4	--	11.8	1.61	1.27
268	"	3066	--	--	4.4	1.2	11.4	1.74	1.27
269	"	3076	2739	.357	10.5	2.9	12.1	1.53	1.27
270	"	3043	2726	.325	8.5	2.5	12.1	1.61	1.21
271	"	3101	2683	.341	8.5	2.9	11.8	1.63	1.25
272	"	3075	2736	.356	10.0	3.4	11.5	1.62	1.32
273	"	3044	2715	.356	6.3	2.7	11.9	1.50	1.34
274	"	3065	--	--	7.6	--	12.0	1.54	1.28
275	"	2992	--	--	12.9	5.1	11.8	1.56	1.32
Avg	0	3039	2700	.351	8.7	3.1	11.9	1.58	1.27

TABLE 1A EGLIN TEST RESULTS

SN 023294 (1:12 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
116	70	3226	2929	.335	6.3	2.1	11.9	1.62	1.44
117	"	3184	2871	.376	10.9	3.8	11.4	1.67	1.51
118	"	3191	2900	.334	6.8	2.5	12.0	1.66	1.38
119	"	3202	2920	.313	1.1	.8	--	--	--
120	"	3209	2916	.323	4.7	2.1	11.9	1.66	1.41
121	"	3193	2900	.333	5.4	1.8	12.2	1.54	1.43
122	"	3209	2925	.316	.8	--	12.0	1.66	1.37
123	"	3152	2863	.332	4.3	1.8	12.5	1.57	1.34
124	"	3235	2940	.332	6.3	2.4	12.2	1.62	1.38
125	"	3222	2937	.314	2.1	1.0	12.0	1.63	1.41
126	"	3241	2926	.365	7.4	2.6	11.6	1.63	1.50
127	"	3223	2911	.370	10.5	3.4	11.8	1.66	1.42
128	"	3181	2869	.363	6.8	2.7	11.9	1.59	1.47
129	"	3224	2966	--	7.2	2.8	11.8	1.63	1.46
130	"	3195	2905	.325	2.8	.6	12.2	1.55	1.43
Avg	70	3206	2912	.338	5.5	2.2	12.0	1.62	1.42

TABLE 1A EGLIN TEST RESULTS

SN 023294 (1:12 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
279	125	3280	--	--	3.8	1.6	11.4	1.74	1.60
280	"	3207	2924	.345	4.4	1.7	11.7	1.62	1.62
281	"	3215	2924	.365	8.8	3.1	11.8	1.60	1.63
282	"	3235	2953	.339	3.6	1.1	11.5	1.76	1.56
283	"	3205	2913	.379	9.5	2.6	11.9	1.60	1.60
284	"	3190	2930	--	4.6	--	--	--	--
285	"	3227	2918	--	10.3	--	--	--	--
286	"	3180	2908	--	7.4	--	--	--	--
287	"	3215	2915	--	7.2	--	--	--	--
288	"	3232	2914	--	10.4	--	--	--	--
Avg	125	3219	2922	.357	7.0	2.0	11.7	1.66	1.60

TABLE 1B EGLIN TEST RESULTS

SN 023199 (1:12 in. Twist)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
223	- 65	3074	2704	.328	5.6	3.3	11.6	1.58	1.16
224	"	2935	2573	.356	10.6	3.1	11.9	1.57	1.10
225	"	3074	--	--	2.4	.6	--	--	1.10
226	"	3100	2735	.327	7.5	1.7	11.9	1.57	1.10
227	"	3058	--	--	7.0	2.0	11.8	1.57	1.13
228	"	3049	2690	.320	4.8	2.0	11.9	1.61	1.08
229	"	3056	2697	.331	7.3	2.3	12.2	1.55	1.06
230	"	2828	2480	.337	4.8	2.4	11.84	1.61	1.09
231	"	2956	2618	.313	4.3	1.8	12.3	1.58	1.03
232	"	3048	2674	.346	7.4	2.1	11.7	1.56	1.16
233	"	3088	2744	.299	2.2	.6	--	--	1.07
234	"	3079	2708	.352	11.1	3.4	11.9	1.56	1.12
235	"	3038	2697	.301	1.5	.6	--	--	1.07
236	"	3012	2638	.358	11.5	3.0	12.1	1.52	1.10
237	"	3083	2714	.332	7.6	2.3	11.9	1.55	1.12
Avg	- 65	3031	2667	.331	6.4	2.1	11.9	1.57	1.10

TABLE 16 EGLIN TEST RESULTS

SN 023199 (1.12 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
136	- 30	3038	2690	.347	10.2	3.7	12.0	1.59	1.17
137	"	3093	2745	.372	7.7	2.0	12.1	1.59	1.14
138	"	3060	2716	.331	5.8	1.9	11.7	1.58	1.22
139	"	3146	2812	.315	4.2	1.1	11.9	1.55	1.20
140	"	3053	2723	.316	4.6	1.9	12.0	1.64	1.14
141	"	3075	2697	.410	16.0	4.3	12.2	1.46	1.21
142	"	3094	2746	.334	5.8	1.8	11.6	1.58	1.25
143	"	3093	2749	.332	8.7	3.2	12.1	1.59	1.15
144	"	3052	2728	.309	3.1	.8	12.1	1.64	1.11
145	"	3013	2681	.326	5.8	1.7	11.8	1.64	1.17
146	"	2965	2616	.381	13.9	3.7	12.4	1.56	1.15
147	"	3116	2761	.341	7.1	--	--	--	--
148	"	3080	2727	.356	11.3	3.6	12.1	1.55	1.16
149	"	3104	2760	.340	7.9	2.4	12.1	1.58	1.15
150	"	3191	2837	.339	10.4	--	11.8	1.56	1.23
Avg	- 30	3078	2732	.343	8.2	2.5	12.0	1.58	1.18

TABLE 1B EGLIN TEST RESULTS

SN 023199 (1:12 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
291	0	3201	2875	.317	3.1	1.3	12.2	1.49	1.28
292	"	3117	2804	.313	5.2	1.8	11.9	1.70	1.18
293	"	3128	2803	.341	5.8	1.0	11.4	1.59	1.37
294	"	3174	2834	.357	12.1	3.3	12.0	1.53	1.29
295	"	3153	2804	.369	12.1	4.3	12.1	1.51	1.30
296	"	3211	2802	--	6.9	2.7	11.7	1.60	1.29
297	"	3113	2799	.312	2.4	.8	12.3	1.42	1.32
298	"	3137	2818	.313	4.8	1.4	12.1	1.58	1.22
299	"	3124	--	--	5.9	2.1	12.3	1.51	1.24
300	"	3065	2760	.303	1.1	.6	11.5	1.82	1.18
301	"	3179	2848	.329	6.1	--	11.9	1.53	1.31
302	"	3161	--	.367	9.1	2.6	12.0	1.60	1.23
303	"	3171	2853	.306	2.2	.8	11.6	1.72	1.24
304	"	3176	2848	.323	5.2	1.4	11.7	1.66	1.24
305	"	3086	2721	.412	15.2	5.0	12.0	1.51	1.31
Avg	0	3144	2815	.336	6.5	2.1	11.9	1.58	1.26

TABLE 1B EGLIN TEST RESULTS

SN 023199 (1:12 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
1	70	3228	2925	.351	8.5	3.1	11.6	1.63	1.51
2	"	3216	2918	.345	7.2	2.3	12.0	1.58	1.45
3	"	3277	2967	.350	7.8	3.0	11.9	1.56	1.48
4	"	3278	2934	.379	12.3	4.5	12.0	1.54	1.49
5	"	3269	2971	.321	3.4	2.5	11.8	1.59	1.50
6	"	3260	2962	.329	3.7	1.6	11.6	1.57	1.55
7	"	3222	--	--	7.2	2.5	11.9	1.59	1.46
8	"	3272	2978	.326	4.2	1.7	12.0	1.60	1.41
9	"	3261	--	--	6.2	--	12.0	1.56	1.47
10	"	3238	2942	.329	4.6	1.7	11.7	1.65	1.45
11	"	3252	2959	.324	3.6	1.3	11.6	1.63	1.50
12	"	3286	2974	.345	5.9	2.1	11.6	1.61	1.51
13	"	3233	2929	.300	7.5	2.7	11.7	1.60	1.50
14	"	3228	--	--	7.6	2.3	12.0	1.56	1.46
15	"	3263	2976	.316	3.6	1.0	12.0	1.58	1.44
Avg	70	3253	2953	.341	6.3	2.3	11.8	1.59	1.48

TABLE 16 EGLIN TEST RESULTS

SN 025199 (1:12 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
269	125	3273	--	--	6.7	1.7	11.5	1.65	1.66
270	"	3299	--	--	7.2	2.5	11.6	1.62	1.67
271	"	3293	2997	.364	6.4	2.8	11.4	1.53	1.82
272	"	3287	2997	.359	6.8	2.4	11.5	1.66	1.65
273	"	3265	2989	.337	4.4	1.2	11.8	1.61	1.61
274	"	3283	2973	--	11.4	--	--	--	--
275	"	3259	2941	--	6.3	--	--	--	--
276	"	3299	--	--	7.9	--	--	--	--
277	"	3275	2969	--	7.3	--	--	--	--
278	"	3278	2876	--	1.0	--	--	--	--
Avg	125	3281	2963	.353	6.5	2.1	11.6	1.61	1.68

TABLE 1C EGLIN TEST RESULTS

SN 789076 (1:14 in. Twist)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s*
238	- 65	2893	2373	.714	31.4	7.6	--	--	--
239	"	2928	2400	.700	32.7	8.0	--	--	--
240	"	2747	2168	.896	35.3	9.7	--	--	--
241	"	3096	2568	--	--	8.0	--	--	--
242	"	2948	2429	.641	--	9.1	--	--	--
243	"	2819	--	--	38.4	--	--	--	--
244	"	3023	--	--	37.1	--	--	--	--
245	"	2768	--	--	--	--	--	--	--
246	"	2993	--	--	36.7	--	--	--	--
247	"	2974	--	--	36.7	--	--	--	--
248	"	2894	--	--	39.7	--	--	--	--
249	"	2938	2300	--	--	10.6	--	--	--
250	"	2958	2390	.753	33.4	10.8	--	--	--
251	"	2914	--	--	38.0	--	--	--	--
252	"	2890	2350	.754	32.9	8.6	--	--	--
Avg	- 65	2919	2372	.743	35.7	9.0	--	--	--

*Effective stability factor

TABLE 1C EGLIN TEST RESULTS

SN 789076 (1:14 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
171	- 30	2882	2453	.514	22.2	7.7	--	--	--
172	"	3062	2564	.632	29.2	9.6	--	--	--
173	"	2846	2378	--	32.9	10.7	--	--	--
174	"	3048	2550	.658	30.3	9.2	--	--	--
175	"	3094	2544	.769	34.4	--	--	--	--
176	"	2995	2595	.440	16.5	6.1	--	--	--
177	"	2983	2595	.653	29.0	8.5	--	--	--
178	"	3045	2502	.761	35.6	12.0	--	--	--
179	"	2963	2446	.743	33.4	9.6	--	--	--
180	"	2991	2542	.570	25.0	7.4	--	--	--
181	"	3015	--	--	31.1	--	--	--	--
182	"	3074	2582	--	27.1	8.1	--	--	--
183	"	3027	2522	.701	30.8	9.2	--	--	--
184	"	3043	2567	.646	27.8	8.4	--	--	--
185	"	3029	2562	.592	26.9	7.4	--	--	--
Avg	- 30	3007	2522	.644	28.8	8.8	--	--	--

TABLE IC EGLIN TEST RESULTS

SN 789076 (1:14 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s*
276	0	3061	2688	.411	13.8	6.1	13.5	1.49	1.05
277	"	3063	2636	.551	26.0	8.4	13.3	1.49	1.08
278	"	3095	2674	.414	17.6	6.4	13.3	1.51	1.07
279	"	3085	--	--	13.3	--	13.1	1.51	1.10
280	"	3036	2607	.510	25.6	8.5	--	--	--
281	"	3028	2611	.529	22.2	8.2	13.2	1.50	1.08
282	"	3066	2642	.525	24.6	8.7	13.7	1.41	1.07
283	"	3102	2734	.406	15.0	4.5	13.5	1.45	1.07
284	"	2944	2554	.505	21.4	6.3	13.5	1.46	1.07
285	"	3042	2610	.557	26.4	9.0	13.1	1.53	1.09
286	"	3048	2693	.423	14.6	8.4	13.4	1.47	1.08
287	"	2982	2545	.565	26.8	4.4	13.5	1.46	1.07
288	"	2994	2623	.435	17.6	5.7	13.5	1.48	1.06
289	"	3011	2606	.504	22.2	7.2	13.7	1.43	1.06
290	"	3156	2764	.451	20.5	7.0	13.0	1.55	1.08
Avg	0	3048	2642	.489	20.5	7.1	13.4	1.48	1.07

*Effective stability factor

TABLE 1C EGLIN TEST RESULTS

SN 789076 (1:14 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (200')* (deg.)	Twist (in.)	C_{M_α}	s
8291	70	3296	3001	.344	9.1	5.1	13.5	1.62	1.12
8292	"	3185	2902	.340	6.4	2.4	13.4	1.62	1.14
8293	"	3246	2981	.318	3.7	1.2	13.4	1.66	1.10
8294	"	3224	2951	.327	5.2	1.7	13.2	1.70	1.11
8295	"	3225	2937	.351	9.0	3.2	13.2	1.68	1.12
8296	"	3214	2914	.369	10.2	5.0	13.5	1.54	1.17
8297	"	3244	2971	.322	5.7	2.4	13.7	1.59	1.09
8298	"	3191	2910	.324	5.7	1.9	--	--	--
8299	"	3252	2934	.399	12.1	5.3	13.3	1.48	1.26
8300	"	3180	2861	.390	13.2	5.3	13.5	1.60	1.14
8301	"	3240	2902	.468	19.5	7.7	13.6	1.50	1.20
8302	"	3214	2929	.346	5.6	2.1	13.4	1.56	1.18
8303	"	3198	2912	.352	8.3	3.4	13.4	1.59	1.14
8304	"	3211	2894	.421	15.2	5.7	13.3	1.56	1.20
8305	"	3232	2940	.358	10.5	3.4	13.4	1.56	1.17
Avg	70	3223	2929	.362	9.3	3.7	13.4	1.59	1.15

*Aerodynamics Range test

TABLE 10 EGLIN TEST RESULTS

SN 789076 (1:14 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
299	125	3239	2928	.367	12.3	4.7	13.3	1.55	1.33
300	"	--	2900	--	--	2.6	--	--	--
301	"	--	2929	--	--	1.7	--	--	--
302	"	--	2886	--	--	5.6	--	--	--
303	"	--	--	--	--	--	--	--	--
304	"	3249	2926	--	5.6	--	--	--	--
305	"	3241	2925	--	11.1	--	--	--	--
306	"	3255	2938	--	6.2	--	--	--	--
307	"	3228	2910	--	6.3	--	--	--	--
308	"	3247	2893	--	--	--	--	--	--
Avg	125	3243	2915	--	8.3	3.6	--	--	--

TABLE 19 EGLIN TEST RESULTS

SN 791707 (1:14 in. Twist)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s*
253	- 65	2834	--	--	37.4	--	--	--	--
254	"	2800	--	--	--	--	--	--	--
255	"	3077	2507	.723	31.9	9.9	--	--	--
256	"	2908	--	--	35.3	--	--	--	--
257	"	2887	--	--	38.0	--	--	--	--
258	"	2982	--	--	--	--	--	--	--
259	"	3041	2459	.773	34.4	9.9	--	--	--
260	"	2968	--	--	39.3	--	--	--	--
261	"	2972	--	--	--	--	--	--	--
262	"	3092	--	--	35.3	10.2	--	--	--
263	"	2918	--	--	33.9	--	--	--	--
264	"	2949	--	--	38.6	--	--	--	--
265	"	2861	--	--	39.3	--	--	--	--
266	"	2895	--	--	36.2	--	--	--	--
267	"	2908	--	--	37.6	--	--	--	--
268	"	3025	--	--	36.2	--	--	--	--
Avg	- 65	2945	2483	.748	36.4	10.0	--	--	--

*Effective stability factor

TABLE 1D EGLIN TEST RESULTS

SN 791707 (1:14 in Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
186	- 30	3009	2571	.522	21.6	7.2	--	--	--
187	"	3031	--	--	31.1	--	--	--	--
188	"	3001	2501	.670	29.8	9.9	--	--	--
189	"	3051	2601	.568	--	7.3	--	--	--
190	"	3096	--	--	25.3	8.0	--	--	--
191	"	2997	2471	.757	31.6	9.6	--	--	--
192	"	3023	2534	.656	27.8	9.3	--	--	--
193	"	2946	2461	.675	29.5	8.9	--	--	--
194	"	2985	2499	.668	29.8	8.5	--	--	--
195	"	2938	2462	.656	28.6	8.4	--	--	--
196	"	3010	2509	.676	28.4	10.0	--	--	--
197	"	2840	2278	.885	33.2	11.2	--	--	--
198	"	3028	2495	.742	33.2	10.8	--	--	--
199	"	2947	2435	.682	28.9	9.3	--	--	--
200	"	3010	2443	.808	33.4	10.7	--	--	--
Avg	- 30	2994	2482	.690	29.6	9.2	--	--	--

TABLE 19 EGLIN TEST RESULTS

SN 791707 (1:14 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s*
106	0	3074	--	--	26.5	8.6	13.8	1.45	1.03
107	"	3006	2564	.613	28.1	9.0	13.5	1.45	1.07
108	"	2994	--	--	18.8	--	13.8	1.44	1.04
109	"	3054	--	--	17.8	6.0	13.3	1.55	1.03
110	"	3070	--	--	24.0	8.7	14.0	1.36	1.07
111	"	2896	2457	.623	27.8	--	13.5	1.47	1.06
112	"	3039	2621	.545	23.5	6.8	13.4	1.50	1.06
113	"	3020	2568	.618	27.5	8.7	13.6	1.48	1.04
114	"	3122	2711	--	20.1	7.5	--	--	--
115	"	3004	2607	.484	20.1	6.2	13.0	1.53	1.10
116	"	3133	2794	.345	5.3	1.0	13.6	1.48	1.05
117	"	3040	2644	.453	17.9	7.5	13.5	1.47	1.06
118	"	3024	2589	.569	24.7	8.1	13.7	1.43	1.06
119	"	2984	2600	.456	16.7	6.9	13.6	1.49	1.03
120	"	3084	2622	.623	27.0	9.4	13.7	1.43	1.06
Avg	0	3036	2616	.533	21.7	7.3	13.6	1.47	1.05

*Effective stability factor

TABLE 1D EGLIN TEST RESULTS

SN 791707 (1:14 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
46	70	3219	2924	.328	4.4	2.1	13.4	1.65	1.10
47	"	3186	2855	.404	13.9	6.0	13.7	1.56	1.13
48	"	3213	2898	.379	12.6	4.4	13.9	1.57	1.09
49	"	3183	2886	.339	7.9	3.8	14.3	1.55	1.04
50	"	3215	2913	.341	7.9	3.8	14.0	1.57	1.07
51	"	3178	2882	.343	7.7	3.3	13.4	1.64	1.12
52	"	3161	2844	.390	12.3	4.1	13.6	1.58	1.13
53	"	3146	2841	.367	10.4	3.5	13.4	1.66	1.11
54	"	3142	2833	.368	10.7	3.8	13.6	1.60	1.1[illegible]
55	"	3193	2858	.414	14.3	6.8	13.6	1.49	1.20
56	"	3194	2890	.348	8.7	4.1	13.5	1.68	1.08
57	"	3202	2891	.359	8.7	4.0	13.3	1.63	1.14
58	"	3158	2844	.375	12.7	5.1	13.3	1.63	1.14
59	"	3170	2876	.330	4.8	2.7	13.5	1.64	1.10
60	"	3214	2914	.338	7.1	2.6	13.6	1.60	1.11
Avg	70	3185	2877	.362	9.6	4.0	13.6	1.60	1.11

TABLE 1D EGLIN TEST RESULTS

SN 791707 (1:14 in. Twist)

(Continued)

Rd. No.	Temp. (deg.)	V_o (ft/sec)	V (228') (ft/sec)	C_D (8')	1st Max. δ (deg.)	Max. δ (228') (deg.)	Twist (in.)	C_{M_α}	s
289	125	3259	2976	.329	2.7	2.1	13.0	1.79	1.21
290	"	3252	2966	.319	1.3	.6	13.2	1.83	1.14
291	"	3178	2930	.435	14.8	6.0	13.7	1.50	1.29
292	"	3275	2998	.325	1.4	.5	13.3	1.70	1.19
293	"	3236	2953	.340	5.1	2.7	13.8	1.64	1.16
294	"	3242	2951	--	6.8	--	--	--	--
295	"	3231	2955	--	5.6	--	--	--	--
296	"	3215	2925	--	11.3	--	--	--	--
297	"	3226	2936	--	6.4	--	--	--	--
298	"	3231	--	--	2.5	--	--	--	--
Avg	125	3252	2954	.350	5.8	2.4	13.4	1.69	1.20

TABLE 2A RESULTS OF THE LIMIT CYCLE TEST
Rifle SN 023199 (1:12 in. Twist)

	175 Meters			253 Meters	
Rd. No.	L.C. (deg.)	V (ft/sec)	Rd. No.	L.C. (deg.)	V (ft/sec)
40	2.1	2559	86	2.8	2162
41	.5	2557	87	.4	2193
42	1.6	2546	88	.6	2148
43	.2	2521	89	1.3	2163
44	.6	2525	90	.2	2216
47	.2	2495	92	1.3	2178
48	.3	2571	93	.3	2175
49	.3	2596	94	2.2	2206
50	.3	2512	95	1.5	2198
51	.4	2556	96	2.0	2166
8316	.5	2515	8353	2.4	1986
8317	.2	2500	8354	.4	2145
8319	.2	2510	8355	.2	2182
8320	.7	2520	8356	2.4	2212
8321	.3	2560	8357	.4	2163
8323	.4	2530	8358	.3	2166
8324	1.3	2565	8359	1.9	2138
8326	.4	2531	8360	2.0	2153
8327	2.2	2455	8361	2.2	2094
8483	.3	2543	8362	.3	2176
8484	.2	2569	8386	2.3	2192
8485	.3	2621	8387	2.3	2193
8486	.1	2540	8388	1.4	--
8487	1.3	2562	8389	2.4	2148
8488	.8	2547	8390	2.3	2176
8489	2.1	2506	8391	.2	2203
8490	1.8	2517	8392	.3	2175
8491	.2	2534	8393	2.2	2119
8492	.2	2513	8494	2.0	2147
8493	.8	2573	8395	.5	2177
Avg.	.69	2538	Avg.	1.37	2164

TABLE 2A RESULTS OF THE LIMIT CYCLE TEST
Rifle SN 023199 (1:12 in. Twist)

(Continued)

Rd. No.	339 Meters L.C. (deg.)	339 Meters V (ft/sec)	Rd. No.	450 Meters L.C. (deg.)	450 Meters V (ft/sec)
2	2.0	1929	72	2.5	1551
3	.2	1938	74	1.4	--
4	2.0	1927	75	2.9	1518
5	.3	1943	76	2.4	1560
6	2.2	1900	77	3.1	1452
8	2.7	1918	78	2.3	1507
9	2.3	1956	81	2.5	1549
10	.3	--	82	3.1	1463
11	2.0	1909	83	.8	1574
12	2.6	1905	84	2.7	1508
8420	2.3	1872	85	.6	1578
8421	.3	1884	8397	2.0	1517
8422	1.6	1887	8398	2.7	1617
8423	2.2	1865	8399	2.6	1599
8424	2.1	1909	8400	2.9	1525
8425	2.3	1877	8401	2.5	1531
8426	.3	1917	8402	2.5	1534
8427	1.6	1891	8403	1.9	1570
8428	2.2	1879	8404	2.2	1472
8429	2.2	1871	8405	2.2	1444
8430	2.4	1896	8407	2.5	1455
8431	2.4	1912	8408	2.8	1595
8432	.2	1925	8409	2.5	1527
8433	2.2	1858	8411	.2	1578
8434	2.4	1900	8412	2.5	1587
8435	1.2	1867	8413	2.9	1543
8436	.2	1901	8414	2.4	1529
8437	2.1	1903	8415	2.9	1518
8438	.2	1923	8416	2.4	1515
8439	2.4	1909	8417	1.8	1589
			8418	2.3	1575
			8419	2.4	1502
Avg.	1.65	1902	Avg.	2.29	1535

TABLE 2B RESULTS OF THE LIMIT CYCLE TEST
Rifle SN 789076 (1:14 in. Twist)

Rd. No.	175 Meters L.C. (deg.)	175 Meters V (ft/sec)	Rd. No.	253 Meters L.C. (deg.)	253 Meters V (ft/sec)
8330	1.8	2483	103	3.6	2128
8331	2.1	2520	105	2.9	1997
8332	2.4	2485	106	2.2	2032
8333	2.2	2447	107	2.7	2141
8334	2.4	2341	108	2.5	2103
8335	2.4	2466	109	2.1	2133
8336	3.4	2408	110	1.8	2182
8338	2.3	2360	111	2.2	2128
8339	2.4	2474	112	2.2	2185
8340	.2	2468	113	2.5	2116
8341	3.1	2384	114	3.1	2017
8342	2.9	2415	8363	2.6	2141
8343	2.1	2465	8364	2.6	2140
8344	.4	2490	8365	1.8	2138
8345	1.4	2496	8366	1.5	2150
8346	2.2	2407	8367	2.6	2067
8347	.6	2490	8368	2.4	2051
8348	2.4	2455	8370	2.4	2026
8349	2.2	2487	8371	2.6	1994
8350	2.2	2417	8372	2.2	2037
8351	.4	2473	8373	2.1	2051
8352	2.1	2501	8375	2.1	2125
8473	2.4	2455	8376	2.9	2126
8474	1.9	2520	8377	2.4	2086
8475	1.5	2504	8378	1.2	2124
8476	2.3	2495	8379	2.5	2186
8477	.6	2501	8380	2.6	2195
8478	.8	2470	8382	2.3	2205
8479	2.4	2496	8383	1.7	2115
8480	3.0	2496	8384	2.6	2055
8481	2.1	2485	8385	2.0	2194
8482	2.1	2444			
Avg.	1.96	2462	Avg.	2.35	2109

TABLF 2B RESULTS OF THE LIMIT CYCLE TEST
Rifle SN 789076 (1:14 in. Twist)

(Continued)

Rd. No.	339 Meters L.C. (deg.)	339 Meters V (ft/sec)	Rd. No.	450 Meters L.C. (deg.)	450 Meters V (ft/sec)
33	2.4	1839	8466	3.3	1449
35	2.5	1785	8467	1.5	1464
37	2.8	1858	8468	3.1	1392
38	3.3	1900	8469	2.8	1418
39	2.1	1846	8470	3.2	1478
8440	2.7	1828	8471	2.6	1435
8441	2.3	1902	8472	3.1	1457
8442	2.3	1805	8494	3.2	1425
8443	2.4	1906	8495	.2	1540
8444	2.3	1764	8496	3.0	1488
8445	2.4	1819	8497	.4	1521
8446	2.4	1815	8498	2.7	1490
8447	2.2	1844	8499	3.0	1465
8448	2.9	1748	8500	3.0	1525
8449	2.9	1792	8501	2.8	1407
8450	1.6	1839	8503	3.0	1459
8451	2.5	1831	8504	2.7	1520
8452	2.6	1758	8505	3.4	1499
8453	2.6	1821	8506	2.8	1494
8454	1.9	1858	8507	2.8	1465
8455	2.4	1806	8508	3.5	1463
8456	2.2	1750	8509	3.3	1521
8457	3.0	1788	8510	2.9	1507
8458	2.4	1812	8511	3.5	1454
8459	2.4	1797	8512	2.6	1480
8460	2.6	1792	8513	3.4	1494
8461	2.8	1813	8514	2.0	1483
8463	2.6	1813	8515	2.4	1569
8464	2.5	1748	8516	--	1509
8465	--	1834	8517	3.3	1491
			8518	2.1	1532
			8519	3.3	1526
Avg.	2.48	1817	Avg.	2.74	1482

TABLE 2C RESULTS OF THE LIMIT CYCLE TEST
Velocities Corrected to 70°F
Rifle SN 023199 (1:12 in. Twist)

Rd. No.	175 Meters V (ft/sec)	Rd. No.	253 Meters V (ft/sec)
40	2559	86	2162
41	2557	87	2193
42	2546	88	2148
43	2521	89	2163
44	2525	90	2216
47	2495	92	2178
48	2571	93	2175
49	2596	94	2206
50	2512	95	2198
51	2556	96	2166
8316	2515	8353	2021
8317	2500	8354	2182
8319	2510	8355	2220
8320	2520	8356	2251
8321	2560	8357	2201
8323	2530	8358	2204
8324	2565	8359	2175
8326	2531	8360	2191
8327	2455	8361	2131
8483	2543	8362	2214
8484	2569	8386	2230
8485	2621	8387	2231
8486	2540	8389	2186
8487	2562	8390	2214
8488	2547	8391	2241
8489	2506	8392	2213
8490	2517	8393	2156
8491	2534	8394	2184
8492	2513	8395	2215
8493	2573		
Avg.	2538	Avg.	2188

TABLE 2C RESULTS OF THE LIMIT CYCLE TEST

Velocities Corrected to 70°F

Rifle SN 023199 (1:12 in. Twist)

(Continued)

Rd. No.	339 Meters V (ft/sec)	Rd. No.	450 Meters V (ft/sec)
2	1929	72	1551
3	1938	75	1518
4	1927	76	1560
5	1943	77	1452
6	1900	78	1507
8	1918	81	1549
9	1956	82	1463
11	1909	83	1574
12	1905	84	1508
8420	1900	85	1578
8421	1913	8397	1540
8422	1916	8398	1642
8423	1894	8399	1624
8424	1938	8400	1548
8425	1906	8401	1554
8426	1946	8402	1558
8427	1920	8403	1594
8428	1908	8404	1495
8429	1900	8405	1466
8430	1925	8407	1477
8431	1941	8408	1620
8432	1955	8409	1550
8433	1887	8411	1602
8434	1929	8412	1611
8435	1896	8413	1567
8436	1928	8414	1552
8437	1930	8415	1541
8438	1949	8416	1538
8439	1935	8417	1613
		8418	1599
		8419	1525
Avg.	1922	Avg.	1551

TABLE 2D RESULTS OF THE LIMIT CYCLE TEST

Velocities Corrected to 70°F

Rifle SN 789076 (1:14 in. Twist)

Rd. No.	175 Meters V (ft/sec)	Rd. No.	253 Meters V (ft/sec)
8330	2483	103	2128
8331	2520	105	1997
8332	2485	106	2032
8333	2447	107	2141
8334	2341	108	2103
8335	2466	109	2133
8336	2408	110	2182
8338	2360	111	2128
8339	2474	112	2185
8340	2468	113	2116
8341	2384	114	2017
8342	2415	8363	2185
8343	2465	8364	2184
8344	2490	8365	2183
8345	2496	8366	2195
8346	2407	8367	2110
8347	2490	8368	2094
8348	2455	8370	2068
8349	2487	8371	2035
8350	2417	8372	2080
8351	2473	8373	2094
8352	2501	8375	2170
8473	2455	8376	2170
8474	2520	8377	2130
8475	2504	8378	2169
8476	2495	8379	2232
8477	2501	8380	2241
8478	2470	8382	2251
8479	2496	8383	2159
8480	2496	8384	2098
8481	2485	8385	2240
8482	2444		
Avg.	2462	Avg.	2137

TABLE 2D RESULTS OF THE LIMIT CYCLE TEST
Velocities Corrected to $70^{\circ}F$
Rifle SN 789076 (1:14 in. Twist)

(Continued)

Rd. No.	339 Meters V (ft/sec)	Rd. No.	450 Meters V (ft/sec)
33	1839	8466	1474
35	1785	8467	1490
37	1858	8468	1416
38	1900	8469	1443
39	1846	8470	1503
8440	1840	8471	1460
8441	1914	8472	1482
8442	1817	8494	1450
8443	1946	8495	1567
8444	1801	8496	1514
8445	1857	8497	1548
8446	1853	8498	1516
8447	1883	8499	1491
8448	1784	8500	1550
8449	1830	8501	1432
8450	1878	8503	1484
8451	1869	8504	1546
8452	1795	8505	1525
8453	1821	8506	1520
8454	1897	8507	1490
8455	1844	8508	1489
8456	1787	8509	1547
8457	1826	8510	1533
8458	1850	8511	1479
8459	1835	8512	1506
8460	1830	8513	1520
8461	1851	8514	1509
8463	1851	8515	1596
8464	1784	8516	1535
8465	1872	8517	1517
		8518	1559
		8519	1553
Avg.	1845	Avg.	1508

TABLE 3 DISPERSION RESULTS

Serial No.	σ (10 rds) mils	σ (15 rds) mils	σ (25 rds) mils
		125°F	
023199	.859	1.223	1.154
023294	.981	.779	.882
789076	.947	1.345	1.466
791707	1.114	1.254	1.205
790787			3.067
Hall			3.638
		70°F	
023199	.847	1.030	1.071
023294	1.016	.768	.954
789076	1.853	1.652	1.891
791707	1.016	1.307	1.203
790787	1.942	1.581	1.752
		0°F	
023199	1.095	.860	1.117
023294	1.110	.980	1.048
789076	3.021	2.599	2.806
791707	.867	1.598	1.334
		-30°F	
023199	1.077	1.207	1.233
023294	1.187	1.025	1.127
789076	2.436	3.832	3.388
791707	3.030	3.403	3.396
		-65°F	
023199	1.746	1.074	1.391
023294	2.099	1.588	1.810
789076	6.833	6.771	6.672
791707	5.497	6.837	6.567
Hall			2.391

TABLE 3 DISPERSION RESULTS

(Continued)

Serial No.	C.I.* (10 rds) in.	C.I.* (15 rds) in.	C.I.* (25 rds) in.
		125°F	
023199	2.04/- .15	1.18/- .08	1.52/- .11
023294	.33/ .70	- .11/ .89	.08/ .81
789076	- 2.10/- 2.89	-1.68/- 4.58	- 1.84/- 3.90
791707	.24/ 1.00	.56/ .57	.43/ .74
790787			1.70/- 1.90
Hall			- .08/- .15
		70°F	
023199	-10.18/ 9.92	-9.87/ 8.96	- 9.99/ 9.32
023294	- 5.25/ 7.95	-5.69/ 8.67	- 5.51/ 8.38
789076	- .22/- 2.17	.05/- .52	- .06/- 1.18
791707	- 9.13/ 6.52	-9.17/ 6.02	- 9.15/ 6.22
790787	- 7.00/ 8.64	-6.62/ 9.45	- 6.77/ 9.13
		0°F	
023199	-10.31/ 11.55	-9.54/ 10.62	- 9.85/ 10.99
023294	- 3.84/ 8.03	-3.80/ 8.58	- 3.82/ 8.36
789076	- 8.49/ 10.47	-7.18/ 9.63	- 7.67/ 9.45
791707	- 8.67/ 9.76	-8.81/ 9.85	- 8.75/ 9.81
		-30°F	
023199	- 7.14/ 10.84	-7.14/ 9.87	- 7.14/ 10.26
023294	- 8.74/ 7.38	-9.14/ 7.98	- 8.98/ 7.74
789076	- 8.41/ 10.38	-9.20/ 8.93	- 8.88/ 9.51
791707	- 7.16/ 9.64	-9.46/ 9.47	- 8.54/ 9.54
		-65°F	
023199	- 8.92/ 9.12	-9.57/ 8.88	- 9.31/ 8.98
023294	-10.49/ 7.77	-9.72/ 7.61	-10.03/ 7.67
789076	- .70/ 4.16	-1.38/ 3.40	- 1.11/ 3.70
791707	- .16/- .80	3.68/ .74	2.20/ .14
Hall			1.87/ 2.58

*Centers of impact at the same range

TABLE 3 DISPERSION RESULTS

(Continued)

Serial No.	σ_1 mils	σ_2 mils	σ_3 mils	Weighted Average mils
		125°F		
023199	.31	.44	.41	.37
023294	.35	.28	.32	
789076	.34	.48	.52	.47
791707	.40	.44	.43	
790787			1.09	
		70°F		
023199	.30	.37	.38	.36
023294	.36	.27	.34	
789076	.51	.46	.53	.47
791707	.36	.46	.42	
790787	.69	.56	.62	
		0°F		
023199	.39	.30	.40	.38
023294	.39	.35	.37	
789076	1.07	.92	.99	.76
791707	.31	.57	.47	
		-30°F		
023199	.38	.43	.44	.41
023294	.42	.36	.40	
789076	.86	1.36	1.20	1.19
791707	1.07	1.20	1.20	
		-65°F		
023199	.62	.38	.49	.56
023294	.74	.56	.64	
789076	2.42	2.39	2.36	2.32
791707	1.94	2.42	2.32	
Hall			.85	

TABLE 4 SUMMARY OF AERODYNAMIC PROPERTIES

Rd. No.	N (in.)	M	$\sqrt{\delta^2}$ (deg.)	C_D	C_{M_α}	$C_{M_q} + C_{M_{\dot\alpha}}$	$C_{M_{p\alpha}}$	C_{N_α}
1-8160	1:14	2.764	5.4	.363	1.588	-2.46	-.06	2.76
1-8161	1:14	2.778	6.1	.357	1.608	-2.60	.00	2.87
1-8192	1:14	2.782	5.8	.361	1.605	-2.04	-.03	2.98
1-8193	1:14	2.841	3.7	.347	1.635	-2.95	.00	2.89
1-8207	1:12	2.735	2.6	.318	1.663	-3.84	.15	2.70
1-8208	1:12	2.768	2.0	.324	1.658	-2.70	-.08	2.85
1-8222	1:12	2.780	1.5	.316	1.645	-4.30	.07	2.88
1-8223	1:12	2.784	1.0	.314	1.630	-3.82	.15	2.33

Rd. No.	$\lambda_1 (10^3)$ (1/ft.)	$\lambda_2 (10^3)$ (1/ft.)	s	K_1 (rad.)	K_2 (rad.)	S_L (in.)
1-8160	+8.67	+ .86	1.19	.047	.081	.042
1-8161	+7.27	+2.72	1.18	.064	.084	.044
1-8192	+6.74	+2.97	1.13	.068	.086	.042
1-8193	+8.23	+2.31	1.18	.038	.058	.031
1-8207	+6.10	+5.04	1.41	.032	.037	.026
1-8208	+7.89	+1.09	1.50	.020	.031	.026
1-8222	+8.85	+3.22	1.50	.015	.023	.020
1-8223	+6.26	+4.27	1.45	.013	.014	.009

NOTE: All values are determined at a point 75 feet in front of the muzzle

TABLE 5 PHYSICAL PROPERTIES						
No.	Wt. (grams)	L (in.)	d (in.)	cg (inches from base)	I_x (gm-in^2)	I_y (gm-in^2)
			Unfired			
1	3.549	.745	.224	.303	.0184	.1145
2	3.529	.742	.224	.300	.0182	.1140
3	3.540	.746	.224	.303	.0182	.1148
4	3.538	.748	.224	.301	.0181	.1154
5	3.547	.735	.224	.299	.0182	.1147
6	3.564	.727	.224	.296	.0185	.1151
7	3.532	.740	.224	.300	.0183	.1139
8	3.559	.746	.224	.304	.0185	.1159
9	3.564	.749	.224	.303	.0185	.1152
10	3.528	.741	.224	.302	.0181	.1145
Avg	3.546	.741	.224	.301	.0183	.1148
			Recovered			
1A*	3.532	.745	.224	.303	.0182	.1141
2A	3.514	.742	.223	.301	.0182	.1130
3A	Not recovered					
4A	3.522	.749	.223	.302	.0180	.1152
5A	3.530	.735	.223	.300	.0181	.1144
6A	3.564	.727	.224	.296	.0185	.1151
7A	3.517	.740	.223	.303	.0181	.1133
8A	3.544	.747	.223	.305	.0181	.1160
9A	3.546	.750	.223	.303	.0182	.1152
10A	3.512	.741	.224	.303	.0179	.1139
Avg	3.531	.742	.223	.302	.0181	.1145
			Recovered			
11	3.534	.750	.223	.306	.0182	.1161
12	3.531	.743	.226	.302	.0183	.1174
13	3.520	.735	.224	.300	.0182	.1128
14	3.545	.751	.223	.306	.0180	.1182
15	3.534	.734	.223	.299	.0182	.1145
16	3.521	.741	.223	.303	.0182	.1139
17	3.561	.743	.223	.298	.0184	.1162
18	3.567	.764	.223	.309	.0183	.1186
19	3.520	.741	.223	.304	.0182	.1132
20	3.524	.752	.223	.303	.0183	.1133
Avg	3.536	.743	.223	.303	.0182	.1154
Avg**	3.534	.742	.223	.303	.0182	.1150

* The A's are rounds recovered from the group having the same number.

**Average for 19 recovered rounds.

TABLE 6 AVERAGE RESULTS

Serial No.	V_o (ft/sec)	$\sigma(V_o)$ (ft/sec)	δ_{max} (deg.)	$\sigma(\delta_{max})$ (deg.)	s	$\sigma(s)$	σ(25 rds) (mils)	N (in.)
				-65^oF				
023199	3032	73	6.4	3.1	1.10	.04	.49	11.9
023294	2983	91	10.7	4.1	1.09	.03	.64	11.9
Total	3007	85	8.5	4.2	1.10	.03	.59*	11.9
789076	2919	92	35.6	2.7	--	--	2.36	--
791707	2945	84	36.4	2.2	--	--	2.32	--
Total	2932	88	36.1	2.4	--	--	2.32*	--
				-30^oF				
023199	3078	54	8.2	3.6	1.18	.04	.44	12.0
023294	3011	62	8.9	3.8	1.18	.04	.40	12.0
Total	3045	66	8.5	3.7	1.18	.04	.41*	12.0
789076	3006	68	28.8	5.0	--	--	1.20	--
791707	2994	59	29.6	3.4	--	--	1.20	--
Total	3000	63	29.1	4.2	--	--	1.19*	--
				0^oF				
023199	3146	41	6.5	4.0	1.27	.05	.40	11.9
023294	3038	44	8.7	4.0	1.27	.05	.37	11.9
Total	3092	69	7.6	4.1	1.27	.05	.38*	11.9
789076	3048	53	20.5	4.9	1.07	.01	.99	13.4
791707	3036	58	21.7	6.1	1.05	.02	.47	13.6
Total	3041	55	21.1	5.4	1.06	.02	.76*	13.5

*Weighted average

TABLE 6 AVERAGE RESULTS

(Continued)

Serial No.	V_o (ft/sec)	$\sigma(V_o)$ (ft/sec)	δ_{max} (deg.)	$\sigma(\delta_{max})$ (deg.)	s	σ(s)	σ(25 rds) (mils)	N (in.)
				70°F				
023199	3252	23	6.2	2.5	1.48	.04	.38	11.8
023294	3205	24	5.6	3.0	1.43	.05	.34	12.0
Total	3229	33	5.9	2.7	1.45	.05	.36*	11.9
789076	3223	30	9.3	4.3	1.15	.05	.53	13.4
791707	3185	25	9.6	3.1	1.11	.04	.42	13.6
Total	3204	34	9.4	3.7	1.13	.05	.47*	13.5
				125°F				
023199	3281	14	6.5	2.6	1.68	.08	.41	11.6
023294	3219	28	7.0	2.7	1.60	.03	.32	11.7
Total	3250	38	6.8	2.6	1.64	.07	.37*	11.7
789076	3243	9	8.3	3.1			.52	--
791707	3234	26	5.8	4.4	1.20	.06	.43	13.4
Total	3237	22	6.6	4.1			.47*	--

*Weighted average

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
U.S. Army Aberdeen Research and Development Center
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
COMPARISON OF THE EXTERIOR BALLISTICS OF THE M-193 PROJECTILE WHEN LAUNCHED FROM 1:12 IN. AND 1:14 IN. TWIST M16A1 RIFLES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)
Maynard J. Piddington

6. REPORT DATE
October 1968

7a. TOTAL NO. OF PAGES
92

7b. NO. OF REFS
7

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. 1T650212D620

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
Memorandum Report No. 1943

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Commanding Officer, U.S. Army Aberdeen Research and Development Center, Aberdeen Proving Ground, Maryland.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
U.S. Army Materiel Command
Washington, D.C.

13. ABSTRACT
The results of an exterior ballistics test of the M193 ball projectile when launched from the M16A1 rifle are presented and discussed. Rifles with twists of 1 turn in 12 inches and 1 turn in 14 inches were used in the tests. Data were gathered from test firings at the small Aerodynamics Range and the Transonic Range of the Ballistic Research Laboratories and from a temporary range set up in the Climatic Hangar at the Eglin Air Force Base, Florida. Tests at Eglin were conducted at air temperatures ranging from +125 deg. F to -65 deg. F.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified

Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aerodynamic characteristics M16A1 rifle Small arms M193 projectile Temperature variations						

Unclassified
Security Classification